UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
WASHINGTON, D. C.

ADVANCE REPORT

on the

SEDIMENTATION SURVEY AND SUSPENDED-MATTER OBSERVATIONS IN LAKE ISSAQUEENA CLEMSON, SOUTH CAROLINA

1940 - 1941

By

G. A. Zwerner, J. W. Johnson
and
E. M. Flaxman

Sedimentation Section
Office of Research
SCS-SS-37
November, 1942

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In cooperation with

Southeastern Regional Office
Spartanburg, S. C.

ABSTRACT

The sedimentation survey of Lake Issaqueena was made as a part of a Nation-wide study of rates and causes of reservoir silting, especially as influenced by soil erosion and land use. This survey was made specifically in connection with (1) a research investigation on the passage of sediment-laden density currents through the lake and their utilization to decrease the rate of silting, and (2) the planning of a conservation program on the drainage area.

Lake Issaqueena is a recreational development of the 23,000-acre Clemson College Land Use project. It is a basin-type reservoir of 1,836-acre-foot capacity on Six Mile Creek, a tributary of the Keowee River in northwestern South Carolina. The 14.02-square-mile drainage basin of the reservoir lies near the inner edge of the Piedmont Upland and is characterized by rolling to hilly topography. The predominant underlying rock is granite which has given rise chiefly to gray to brown sandy loams and clay loams. At present, 49.7 percent of the area is cultivated, 4.6 percent is idle, 5.0 percent is in pasture, 40.2 percent is forested, and 0.5 percent is farmyards and urban areas. The area has been subject to moderate to very severe field, road, and stream-bank erosion.

The reservoir sediment ranges in texture from gravel to clay. Laboratory studies of the sediment showed median diameters of from 4.0 millimeters on the main stream delta to less than 0.0005 millimeter near the dam. The volume weight of the sediment ranges from 35 to 70 pounds per cubic foot. Average depths range from 1.06 feet on the range nearest the dam to a minimum of about 0.3 foot over the wide middle reaches and to a maximum of 10 feet on the delta and major arm.

The survey revealed that a total of 88 acre-feet (141,970 cubic yards) of sediment had accumulated in the reservoir at an average rate of 149.24 cubic feet annually per acre of drainage area, entailing an annual storage loss of 1.65 percent, or a total of 4.79 percent to the date of survey.

The high rate of sedimentation indicated by the survey points to an urgent need for the adoption of soil-conserving measures on the agricultural lands and the protection of roadside ditches and stream banks.

The program of suspended-matter sampling shows that the passage of density currents through the lake occurs rather frequently. The results of the program demonstrate the desirability of wasting water of high sediment content as usually existing in the lower part of the storage space, either by general settling of sediment, or by the occurrence of an underflow through sluice gates. Although the actual amount of sediment vented through the gates was not large, it is of

importance to note that a much larger amount, perhaps two to five times as much, could have been vented had the discharge through the gates been controlled for this particular purpose.

INTRODUCTION

This report is one of a series of advance reports on sedimentation surveys of representative reservoirs in the United States made by the Sedimentation Section, Office of Research, Soil Conservation Service. Each reservoir survey is a part of a Nation-wide study of the condition of American reservoirs with respect to storage reduction by sedimentation. The broad objectives of these studies are to determine rates of reservoir sedimentation and sediment production from drainage areas as an index to past and potential damages, and to develop a basis for the planning of methods of silting control and conservation of water-storage resources. The survey of Lake Issaqueena was made specifically in connection with a research investigation on the passage of sediment-laden density currents through the lake, and a survey of the drainage area to plan a program of erosion control designed to reduce the turbidity of the lake water, and thereby permit use of the lake for recreational purposes.

The sedimentation survey of Lake Issaqueena[1] was made during the period April 11-17, 1941, by a field party consisting of G. A. Zwerner, E. M. Flaxman, A. T. Talley, W. F. Witzgall, and three temporary assistants. R. G. Grassy made all analyses of sediment samples at the Enoree River sediment-load station of the Sedimentation Division at Greenville, S. C. Carl B. Brown, head of the Sedimentation Section, made all arrangements for the survey, and J. W. Johnson, hydraulic engineer of the Sedimentation Section, prepared the chapter on suspended-matter observations.

M. W. Lowry, Chief, Regional Project Plans Division, and Hugh A. Brown, Assistant Chief, Regional Farm Planning and Management Division, cooperated in furnishing maps, information, and supplies, and arranged for labor to assist in the survey. Partial results of a planning study by Hugh A. Brown are used in this report.

A detailed Soil Conservation Survey was made of the entire watershed by the Regional Division of Physical Surveys. Field work by E. N. Miller, E. A. Burgess, L. E. Aull, R. B. Fickling, W. E. Jones, and S. B. Rochester.

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[1]A legendary Indian heroine's name.

GENERAL INFORMATION

Location (fig. 1):

State: South Carolina.

County: Pickens.

Distance and direction from nearest city: The dam is 6 miles northwest of the city of Clemson, and 3 miles from United States Highway No. 76.

Drainage and backwater: The reservoir is impounded on Six Mile Creek. One-third of a mile below the dam Six Mile Creek empties into the Keowee River, which becomes the Seneca River a few miles below Clemson. The Seneca River joins the Tugaloo River at the Georgia-South Carolina State line to form the Savannah River.

Ownership: Lake Issaqueena and approximately 2,000 acres of the 8,857-acre watershed is owned by the United States Department of Agriculture. The lake area is a part of a 27,000-acre Land Utilization Project leased to Clemson College under the terms of a 95-year cooperative and license agreement.

Purpose served: Recreation.

Description of dam (fig. 2):

Lake Issaqueena is impounded by a cyclopean-concrete, gravity-type dam, 325 feet in over-all length and 51-1/2 feet in height above bed-rock. Its thickness at the top is 3 feet 6 inches, and the maximum thickness at the base is 38 feet 2 inches. The upstream face has a 1:12 batter, and the downstream face has an 8-1/2:12 batter. The dam is situated in a narrow gorge-like section of the stream valley.

The spillway section of the dam is located approximately in the middle of the structure and is 100 feet in length. A training wall is located on either end of the spillway lip running from the top edge of the dam to the plunge pool below. The spillway section has the same slopes as the dam, both upstream and downstream. The spillway crest is 44-1/2 feet above the original bed-rock foundation or 7 feet below the top of the dam. The spillway was constructed for a maximum discharge of 4,668 cubic feet per second.

One 30-inch corrugated iron pipe sluiceway and one 24-inch steel pipe penstock are located in the dam with the center of each orifice 34 feet below spillway crest. The discharge through these outlets is controlled by manually operated, rectangular, cast-iron gates located on the upstream face of the dam (fig. 3).

The total cost of construction of the dam and lake was $124,438.53 which is broken down into labor, $63,346.34; material $54,038.27; and equipment, $7,085.92.

Period of storage: The gates in the dam were closed and storage began in June 1938. The average date of this survey was April 15, 1941. The period of sedimentation at the date of survey was 2.9 years.

Length of lake: (Basin proper, not including the stream channel above the basin, 0.15 mile in length, in which water is impounded.)

Original	1.40 miles
At date of survey	1.29 miles
Reduction by sedimentation	0.11 miles

Area of lake at spillway stage:

Original	117 acres
At date of survey	114 acres
Reduction by sedimentation	3 acres

Storage capacity to spillway level:

	Acre-feet
Original	1,836 (598,262,436 gal.)
At date of survey	1,748 (569,587,548 gal.)
Reduction by sedimentation ..	88 (28,674,888 gal.)

General character of reservoir basin.

The lake basin (fig. 2) consists of a steep-sided, narrow gorge at the dam, which extends upstream approximately 650 feet with submerged banks sloping more than 100 percent, and a broader basin upstream from the gorge section. The lower gorge section of the lake has an average width of 300 feet. The steep-sided bank extends well above crest along practically all the right shore line (looking upstream); however, extensive grading on the left shore line has created a more gentle slope for recreational use. Immediately above the gorge section the basin widens out to form a trough-like section with side slopes ranging from 50 to 100 percent which grade inward to gentle slopes, and a flat flood

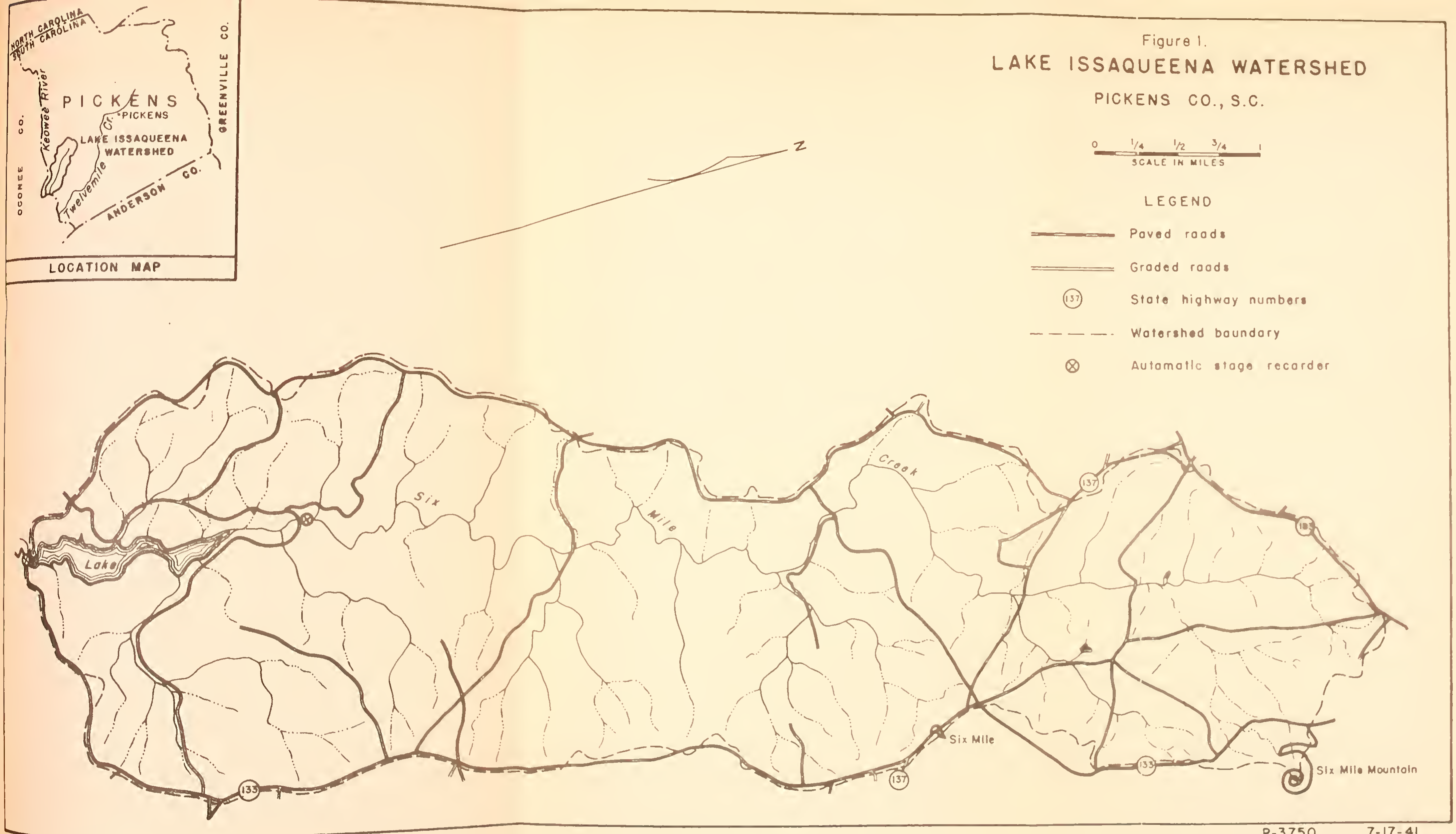
Figure 1.
LAKE ISSAQUEENA WATERSHED
PICKENS CO., S.C.
0 1/4 1/2 3/4 1
SCALE IN MILES
N
LEGEND
Paved roads
Graded roads
137 State highway numbers
Watershed boundary
Automatic stage recorder
LOCATION MAP
NORTH CAROLINA
SOUTH CAROLINA
PICKENS
PICKENS
LAKE ISSAQUEENA WATERSHED
Keowee River
Twelvemile Cr.
OCONEE CO.
GREENVILLE CO.
ANDERSON CO.
Lake
Six
Mile
Creek
137
133
185
Six Mile
Six Mile Mountain

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Figure 2.--View of Lake Issaqueena Dam and spillway, showing the well-sodded and heavily wooded shore line.

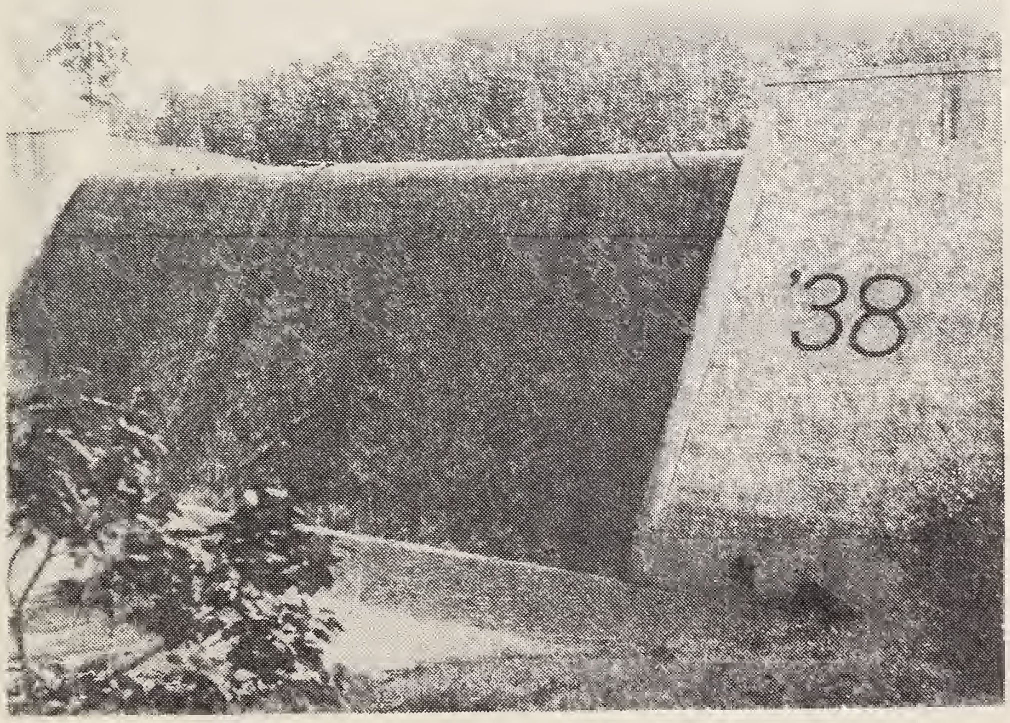


Figure 3.--View of the downstream side of Lake Issaqueena Dam, showing outlets of the two gates.

plain averaging 400 to 450 feet in width. This type of basin extends from the gorge area to a point 1,700 feet above the dam where a much broader flood plain of 900 to 1,000 feet in width begins and extends to 3,600 feet above the dam. The below-crest side slopes of the valley, even in this section of the basin, are relatively steep, averaging close to 40 or 50 percent. The width of the basin itself at spillway crest elevation averages 1,900 feet. From the last-named point to the head of the basin proper, the lake narrows to an average width of 495 feet. The side slopes become more gentle and the flat flood plain extends across practically the entire basin. The basin proper has a length of 7,340 feet above the dam, but for 800 feet farther, backwater occurs at crest stage in the original stream channel, which is 40 to 50 feet wide.

A single tributary arm of major importance, 700 feet in length and 620 feet in width at its lower end, enters the main basin approximately 5,300 feet above the dam.

A strip of land adjacent to the shore line has been cleared of underbrush but has a good cover of sod. This strip has been reforested in pines so that wave erosion contributes only an insignificant amount of sediment. Rather severe washing is now taking place, however, on several areas where road cuts have been made and abandoned or left untreated, especially on the road curve near the boat house. The flat flood plain above the lake basin is covered with willows and tall grass, but the islands formed within the lake area are bare.

The original stream channel followed a rather straight to gently meandering course down the valley near the center of the flood plain through the reservoir area. The average original gradient of the stream was 27.9 feet per mile from the head of the basin proper to the dam.

Area of drainage basin: The drainage area of Lake Issaqueena comprises 8,857 acres or 13.8 square miles, excluding the lake area, as determined from planimetric maps prepared from aerial photographs by the Regional Cartographic Division of the Soil Conservation Service.

General character of drainage basin.

Geology.--The drainage area tributary to Lake Issaqueena lies near the western edge of the Piedmont Plateau province. The geology of this area has not been mapped, but a study of the United States Geological Survey geologic folio of the Pisgah quadrangle, directly north of the Pickens quadrangle, which includes the Six Mile Creek drainage area, has given a means of identifying the local geologic formations.

The strike of the Whiteside granite on the Pisgah quadrangle, northeast and southwest in common with that of other formations in the area, indicates that it underlies much of the middle and upper portions of the drainage area. The Whiteside granite is described in the Pisgah

folio as consisting chiefly of orthoclase and plagioclase feldspar, with quartz, muscovite, and biotite in order of decreasing importance. The rock is fine- to medium-grained, varying from white to gray in color. The granite contains many large and irregular inclusions of older gneisses into which it is intruded. Small dikes and patches of pegmatite are also present. The granite itself is gneissic. The geology of the Pisgah quadrangle also indicates that the more highly metamorphosed Henderson granite may outcrop in the area. At the dam site the rock is an orthoclase biotite schist, a type included in the Carolina gneiss, as mapped in this region.

Topography and drainage.--The drainage area is on the rolling to hilly, maturely dissected upland of the Piedmont province. It is an elongated area of roughly parallel east-west divides extending 7.9 miles above the dam and having an average width of 1.7 miles. The main stream occupies a circuitous channel west of the center of the watershed; its many tributaries form a dendritic pattern. The lower two-thirds of the area includes the more hilly topography characterized by steep-sided valleys and streams of high gradient flowing over bedrock. In the upper one-third of the drainage area, the topography is more gently rolling. In this section, which is almost entirely under cultivation, the streams have a lower gradient and have developed small flood plains, as has Six Mile Creek. The almost continuous flood plain on the main stream varies from approximately 100 to 700 feet in width.

Along the northern divide is a prominent, conical monadnock known as Six Mile Mountain, which rises 600 feet or more above the upland level. The maximum range in relief in the drainage area is from 679.5 feet above sea level on the spillway of the dam to more than 1,600 feet on Six Mile Mountain, but the more significant difference in elevation from the dam to the upland level at the head of the drainage is about 425 feet. Divides are comparatively narrow but well-rounded and rock outcrops are rare except on Six Mile Mountain and in stream channels in the lower section.

Table 1 shows the distribution of slope classes in the watershed.

Table 1 1/--Distribution of slope classes in Lake Issaqueena watershed.

Slope classes	Area	
	Acres	Percent
A slopes, 0-2 percent	296	3.3
B slopes, 2-7 percent	1,137	12.8
BB slopes, 7-10 percent	1,971	22.3
C slopes, 10-14 percent	1,566	17.7
D slopes, 14-25 percent	2,542	28.7
E slopes, 25 percent and over	1,345	15.2
Total	8,857	100.0

1/ Compiled from detailed conservation survey made by Regional Physical Surveys Division.

Soils.--A soil survey of Pickens County was made in 1937, but the results have not been published. The soils of the reservoir drainage area were mapped as a part of the conservation survey and data on the areas occupied by major soil groups are given in table 2.

Table 2 1/--Distribution of soil groups in Lake Issaqueena watershed.

Soil groups	Area	
	Acres	Percent
Well-drained, first-bottom and recent colluvial soils	361	4.1
Red to brown clay loams	2,453	27.7
Gray to brown sandy loams	5,985	67.6
Soils with little natural surface or subsoil development	7	-
Soils with imperfect drainage	51	.6
Total	8,857	100.0

1/ Compiled from detailed conservation survey made by Regional Physical Surveys Division.

Land use.--Land use is shown in table 3 and figure 4.

Table 3.[1/]--Distribution of the land use classes in Lake Issaqueena watershed.

Land use	Area	
	Acres	Percent
Cropland	4,396	49.7
Idle land	409	4.6
Pasture	445	5.0
Woodland	3,564	40.2
Farmyards and urban areas	43	.5
Total	8,857	100.0

1/ Compiled from detailed conservation survey made by Regional Physical Surveys Division.

The watershed may be divided into 3 well-defined sections of land use. The lower third surrounding the reservoir is nearly all forested with only a small area classified as idle land. The middle third is approximately 50 percent forested, 30 percent cultivated, and the remainder is pasture and idle land. The upper third, which is less rolling, is nearly 90 percent under cultivation with only small patches of pasture and forested area. In the development of a Land Utilization project, the Federal Government has purchased 2,137 acres for retirement from agricultural use in the lower drainage area.

A recent study (4) of 10 rural school districts in the western part of Pickens County, which includes the area tributary to Lake Issaqueena, provided some pertinent information on the farming community. This section was occupied by Scotch, Irish and English settlers in the latter part of the eighteenth century, and the present population is largely composed of their descendants. Based on the 1936-37 survey, the average size of farm controlled by each farm family was found to be 42.3 acres. The cash income is derived chiefly from cotton, an average of 5.2 bales being produced per farm. Corn, with an average production of 120.5 bushels per farm, is the next most important crop. The average annual income per family is not more than $325.

Figure 4.

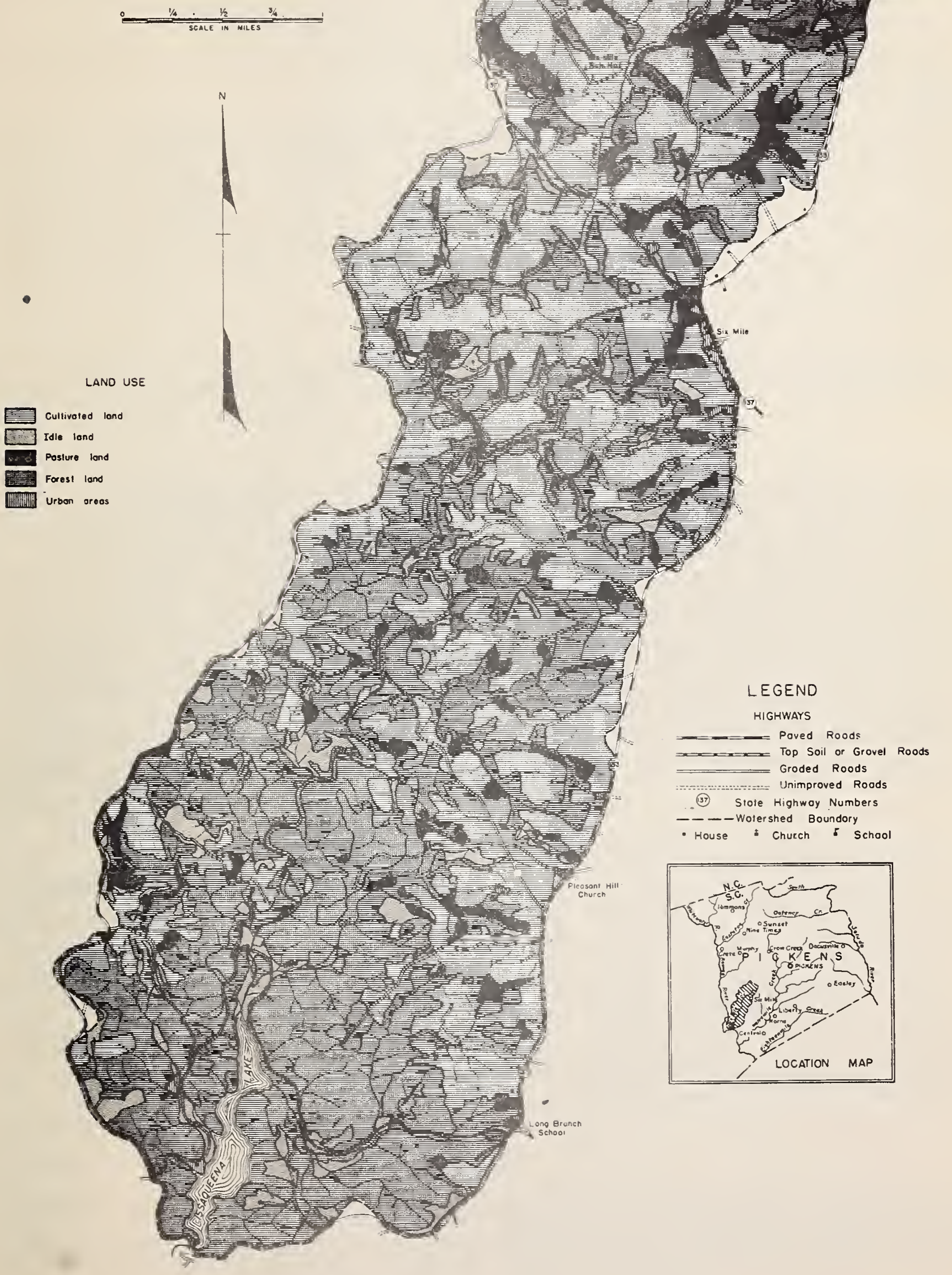
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

LAND-USE MAP

LAKE ISSAQUEENA WATERSHED

(FROM CONSERVATION SURVEY BY REGIONAL PHYSICAL SURVEYS DIVISION)

SIX MILE CREEK
PICKENS CO., S.C.



Erosion conditions.--Table 4 shows the distribution of erosion groups of the Lake Issaqueena watershed.

Table 4.[1/]--Distribution of erosion groups in Lake Issaqueena watershed.

Erosion groups	Area	
	Acres	Percent
Recent alluvial or colluvial deposits	400	4.5
Slight erosion - (2.27)	720	8.1
Moderate erosion - 12 7, 3.37	1,250	14.2
Severe erosion - 3 7, 33, 337	3,626	40.9
Very severe erosion - 33 7, 4.47, 4 7, 4 8 ..	2,861	32.3
Total	8,857	100.0

1/ Compiled from detailed conservation survey made by Regional Physical Surveys Division.

The characteristics of erosion in the area are further described in a report by Hugh A. Brown[2], which shows that moderate stream-bank and serious road erosion is occurring in the watershed. It was found that 21,186 linear feet of banks on the main stream and three of the main headwater tributaries were caving badly, the major cause being cultivation or pasturage of land adjacent to the channel. Roads, road banks, and road ditches were found to be major sources of reservoir sediment, an estimated 175,990 feet or 33.3 miles being in need of protection. Serious gullying occurs only in ditches along farm or field boundaries. The location of roads and stream banks requiring treatment is shown in figure 5, and examples of these processes are shown in figures 6 and 7.

The survey determined the use capability of the land as shown in figure 8. Five capability classes are recognized in the area. The land in classes I to IV is suitable for cultivation. The land in class I can be used without special conservation practices, in class II with simple practices, class III with complex or intensive practices, and class IV is suitable for occasional or limited cultivation. The land in classes V to VIII is not suitable for cultivation. Out of the last group only class VII is recognized in the Lake Issaqueena watershed and is described as land that should be severely restricted with or without special practices.

2
Brown, H. A. Report of a Planning Study of Six Mile Creek Watershed Above Clemson, S. C. U. S. Soil Conserv. Serv. Reg. 2 Farm Planning and Management Division. 1941. (Unpublished.)

The survey revealed that 40 to 61 percent of the watershed is suitable for general farming with proper conservation practices, 28.04 percent should be removed from clean cultivated crops because of steep slopes or other undesirable features and 31.35 percent is now protected by, and should remain in woodland or pasture.

Mean annual rainfall:

The United States Weather Bureau has rainfall data from two stations near Lake Issaqueena. One station at Clemson College, Oconee County, 6 miles southeast of the dam, which has a 39-year continuous record through 1940, shows an average annual rainfall of 53.27 inches. The second station at Walhalla, Oconee County, approximately 15 miles northwest of the Lake Issaqueena dam, with a 27-year continuous record through 1940, shows an average annual rainfall of 53.39 inches.

History of storage:

Lake Issaqueena is one of the principal features of the 23,000-acre Clemson College Land Use project begun in 1934 by the United States Department of Agriculture and Clemson College. The purpose of the project has been to develop this tract of worn-out farms and idle land into productive forests, pastures, and public recreation areas as a contribution to the social and economic welfare of the people of this region.

The lake was completed in 1938 to provide fishing, boating, and picnic facilities to the 130,000 people living within a 30-mile radius of Clemson, S. C. It was originally contemplated that the lake should also provide swimming facilities to the visitors, and a bathhouse, diving pier, and beach were constructed at the time the dam was built. The authorities have not thus far permitted bathing, however, because of the marked turbidity of the water.

In 1938, when the water level first reached spillway crest stage, the lake was clear. With the first heavy inflow, a patch of very turbid water was observed at the head of the lake. As more large inflows occurred, the front of this area of brown muddy water moved farther down the lake, and after the exceptionally heavy rainfall and resulting large inflow of August 13-15, 1940, the lake was completely filled with turbid water.

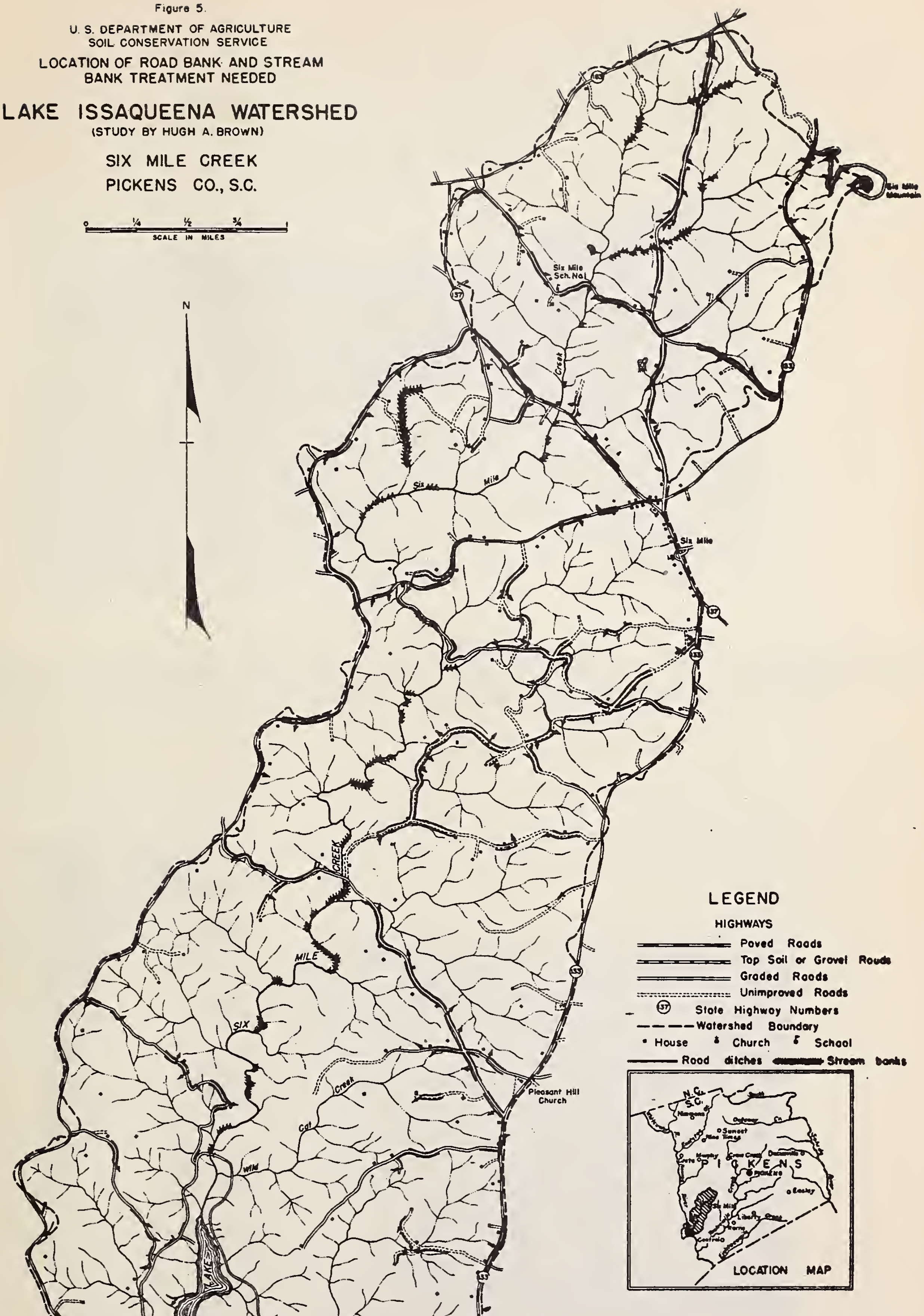


Figure 5.
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
LOCATION OF ROAD BANK AND STREAM BANK TREATMENT NEEDED
LAKE ISSAQUEENA WATERSHED
(STUDY BY HUGH A. BROWN)
SIX MILE CREEK
PICKENS CO., S.C.

Figure 6.--Stream channel with eroding banks, one of the principal sources of reservoir sediment from Lake Issaqueena watershed.

Figure 7.--Roadside erosion in Lake Issaqueena watershed, one of the major sources of reservoir sediment.

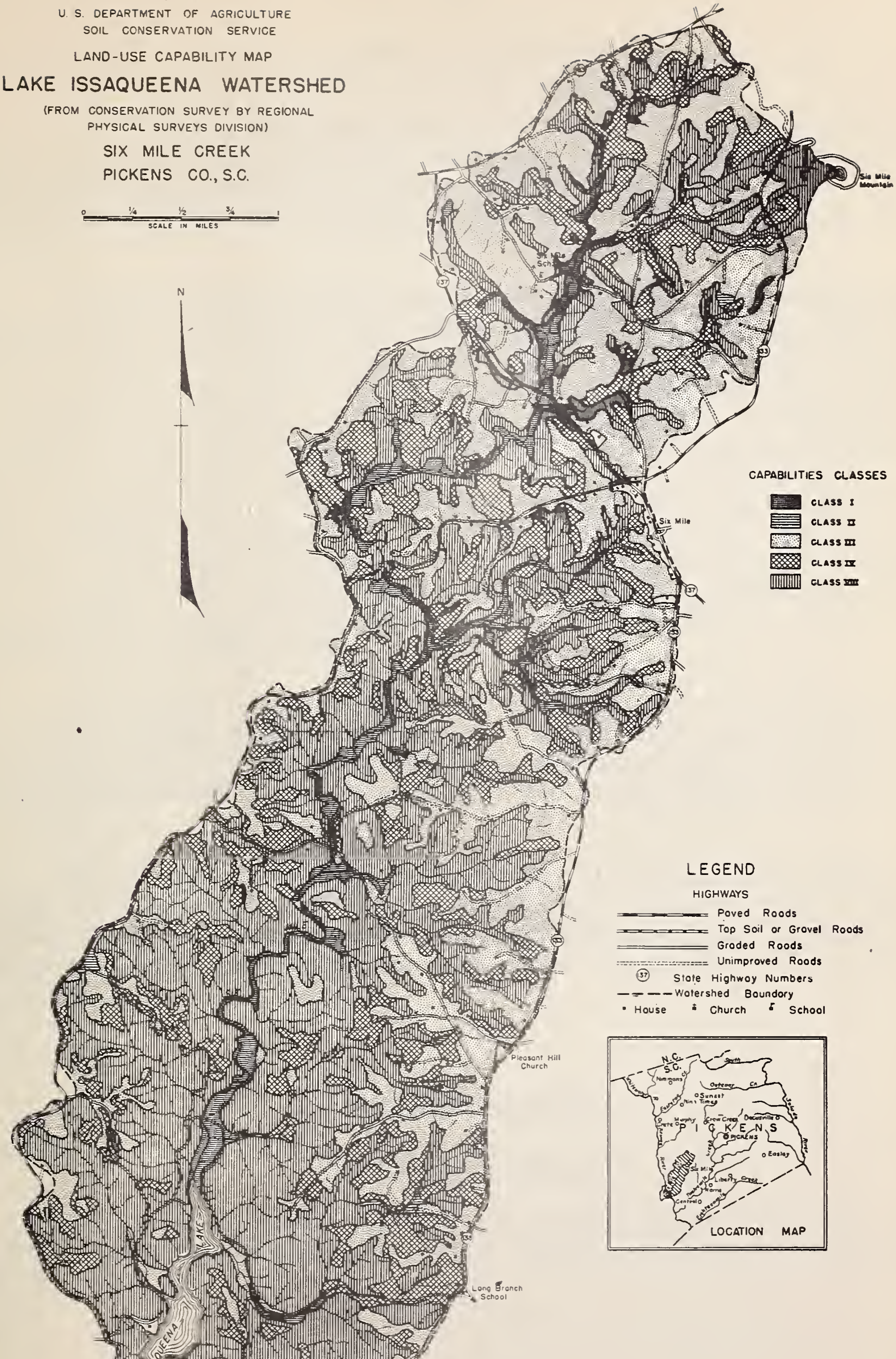
Figure 8.
U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

LAND-USE CAPABILITY MAP

LAKE ISSAQUEENA WATERSHED

(FROM CONSERVATION SURVEY BY REGIONAL PHYSICAL SURVEYS DIVISION)

SIX MILE CREEK
PICKENS CO., S.C.



METHOD OF SURVEY

The original storage capacity and volume of sediment in Lake Issaqueena were determined by the range method of survey (3) for the area covered by bottom-set beds, and by the contour method for sections where deltas were forming at the head of the lake and on one main arm.

A triangulation control system of 22 stations was extended from a chained base line 750 feet in length, between triangulation stations 1,000 and 1,001. Chained check lines were made between triangulation stations 1,010 and 1,011 and also across the dam and spillway. From this network of stations a secondary traverse was used to establish 20 ranges for the measurement of water depths and sediment thickness. Sufficient control was established for locating and determining by stadia the elevations of 57 points used in contouring the delta segments. Mapping was done on two 18 by 24-inch plane-table sheets at a scale of 1 inch equals 200 feet. A 6-foot sectional sediment-measuring spud was employed in making direct measurements of sediment thickness on all ranges. A screw-type auger was used in measuring sediment thickness in the delta areas.

All triangulation stations and range ends were permanently marked with bronze tablets placed in concrete. Each marker, bearing the legend "U. S. Department of Agriculture, Soil Conservation Service, Sedimentation Studies" was stamped with the identification number of the station.

Twenty samples of lake sediment were collected from various sections of the lake, using the Talley, Eakin, and check-valve samplers, for mechanical analyses and volume-weight determinations. Several samples were taken at most points using the various types of samplers as a check against one another.

SEDIMENT DEPOSITS

Character of Sediment

The location, water content, and volume-weight relation of 20 sediment samples collected from bottom deposits in Lake Issaqueena are shown in table 5.

Table 5.--Analyses of sediment samples collected from Lake Issaqueena, Clemson, S. C.

Sample No.[1/]	Range	Distance from left shore	Weight of dry solids per cubic foot of deposits
		Feet	Lbs.
1	5	310	32
2	5	310	35
3	7	505	35
4	7	550	37
5	7	615	36
6	7	630	35
7	7	600	36
8	7	605	35
9	7	615	36
10	7	615	36
11	7	630	32
12	7	600	33
13	12	264	39
14	12	265	39
15	14	253	41
16	14	253	41
17	15	110	40
18	16	270	57
19	Sandbar-Seg.16		89
20	Sandbar-Seg.16		78

1/ Samples 1 and 3 to 7 collected with Eakin sampler, sample 2 with check-valve type, samples 8 to 18 with Talley type, and 19 and 20 were grab-samples.

The sediments are sharply divided into delta and bottom-set deposits. The deltas, which are found in segments 15 and 16 of the main channel and segments 19 and 20 of the main side arm, have volume-weights averaging from 48.5 to 70 pounds per cubic foot. The bottom-set deposits, covering the remaining sections of the reservoir, have volume-weights ranging from an average of 35 pounds per cubic foot near the dam to 41 pounds per cubic foot immediately below the delta areas. The total weight of sediment in the reservoir basin was determined as 96,125 tons, using prorated averages for the sediment, beginning at the dam with 35 pounds per cubic foot and increasing to a maximum of 70 pounds per cubic foot for the main delta deposits. As the total calculated volume of sediment was 88.58 acre-feet, this gives an over-all average volume weight of 49.82 pounds per cubic foot.

Mechanical analyses were made of composite samples prepared from the 20 samples collected for volume-weight determinations. The results of these analyses are shown in the curves in figure 9. Curves A and B show analyses of samples collected from the delta areas and curves C - G show results of samples of bottom-set deposits. The decrease in mean grain size of the sediment down the reservoir is plainly illustrated by the gradation from curve A, based on a sample taken in the sand bar on the delta area in segment 16 and composed of gravel and sand from 4.0 to 0.05 millimeter, to curve G. taken a short distance above the dam and composed of silt and clay not larger than 0.05 millimeter with 30 percent less than 0.0055 millimeter. Curve H shows a composite analysis of all suspended-load samples taken from Six Mile Creek.

The delta areas have gravel and sand bars exposed above crest in segments 16 and 20. Ranges 16 and 20 cross the delta fronts. The toes of these deltas are in segments 15 and 19, and pronounced deltaic deposits are lacking on ranges 15 and 19.

The colors of the bottom-set deposits are light yellow for the thin top layer of recent deposits (following August 1940 flood), which range from a trace to 0.8 foot in thickness, and chocolate brown for the older deposits found in the deeper points along the ranges and especially on the 4 ranges immediately above the dam. The sands and gravel, which make up the bars and islands in segments 16 and 20 are light in color, yellow to white, and in the ponded channel areas have been washed clean of all silt and clay.

Distribution of Sediment

The sediment, distributed as shown in table 6, may be divided into delta and lower basin or bottom-set deposits. The delta deposits comprise 47.84 percent of the total reservoir accumulation, and occur in segments 15, 16, 19, and 20. The toes of these deltas are traversed by ranges 16 and 20. The width, areas, and average depth of each of the 20 sediment ranges have been tabulated in table 7 from which the curves in figure 10 were drawn. The two lower curves of figure 10, namely, the average depth profile and the curve representing the percentage of cross-sectional area lost on each range, indicate the delta of segments 15 and 16 by the large hump that begins at about R-15 on each curve.

A thick deposit of sediment, which occurs immediately upstream from the dam, is a result of sediment-laden density currents that flow along the bottom of the lake and drop their load on reaching the face of the dam (6). If the gates had been open for longer periods in the past, it can be reasonably assumed that much of this lower basin deposit would have been vented through the dam. The average depth of sediment on range 1 was 1.06 feet and on range 3 was 0.67 foot. From range 4 on upstream through the main body of the lake the average depths are small, about 0.35 to 0.40 foot. At range 14 the average depth of sediment was 1.05 feet and the two ranges, R-15 and R-16, on the main

delta, have average sediment depths of 1.71 and 2.62 feet, respectively. The two ranges 19 and 20 covering the side delta have average sediment depths of 0.67 and 1.65 feet, respectively.

Table 6.--Distribution of storage capacity and sediment in Lake Issaqueena, Clemson, S. C.

	Storage capacity			Sediment	
	Original	1941	Loss	Volume	Proportion of total
	Acre-feet	Acre-feet	Percent	Acre-feet	Percent
Lower basin:					
Segments 0-14, 17, 18	1,748.25	1,702.05	2.64	46.20	52.16
Delta sections:					
Segments 15-16..	59.66	24.08	59.64	35.58	40.17
Segments 19-20..	28.42	21.62	23.93	6.80	7.67
	88.08	45.70	48.12	42.38	47.84
Total	1,836.33	1,747.75	4.82	88.58	100.00

The cross-sectional distribution of the sediment deposits is illustrated by the 4 representative ranges shown in figure 11. Range 1 which is 100 feet upstream from the dam, gives evidence of the heavy underflow deposit. Range 16, a delta area range, has the thick sediment depths found on the downstream slope of the main delta. The thin sediment deposits covering the large bowl-shaped center section of the lake are shown on range 7. The maximum sediment depth of 10 feet occurs in the contoured delta area above range 16. In the side arm, the maximum depth in the contoured area above range 20 is 6.8 feet. The large volume of coarse sand is indicative of high flood discharge as well as such erosional debris sources as gullies, road ditches, and stream banks where concentrated flows of water act as eroding agents.

Curve	Location of sample		Distance below head of backwater
A	Delta		550 ft.
B	Range	16	825 "
C	Range	14	1,550 "
D	Range	12	2,400 "
E	Range	7	5,225 "
F	Range	5	6,100 "
G	At dam		7,400 "
H	Composite of all suspended-load samples taken from Six Mile Creek		

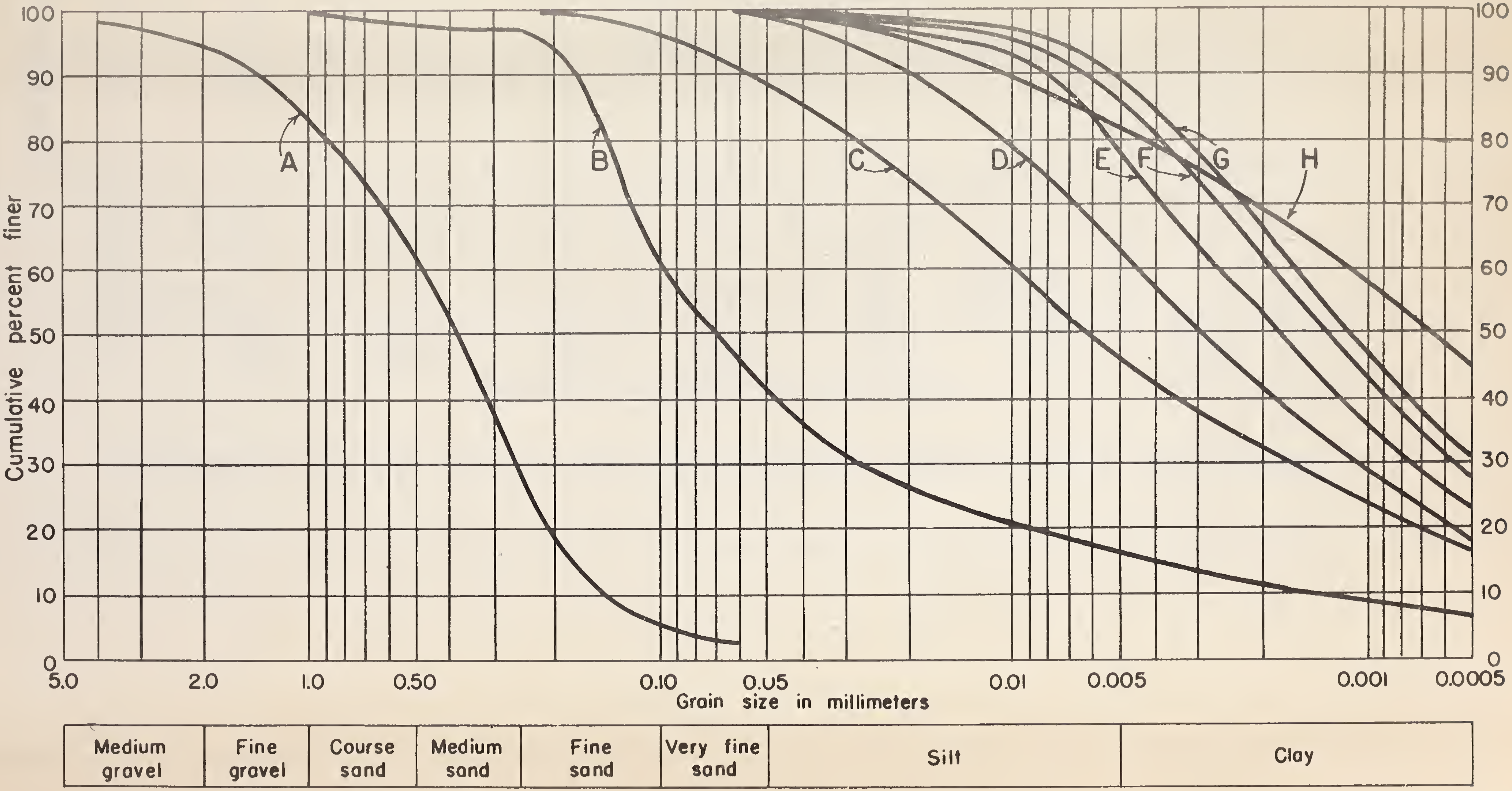


Figure 9 —Mechanical analysis of sediments in Lake Issaqueena, Pickens Co., S. C.

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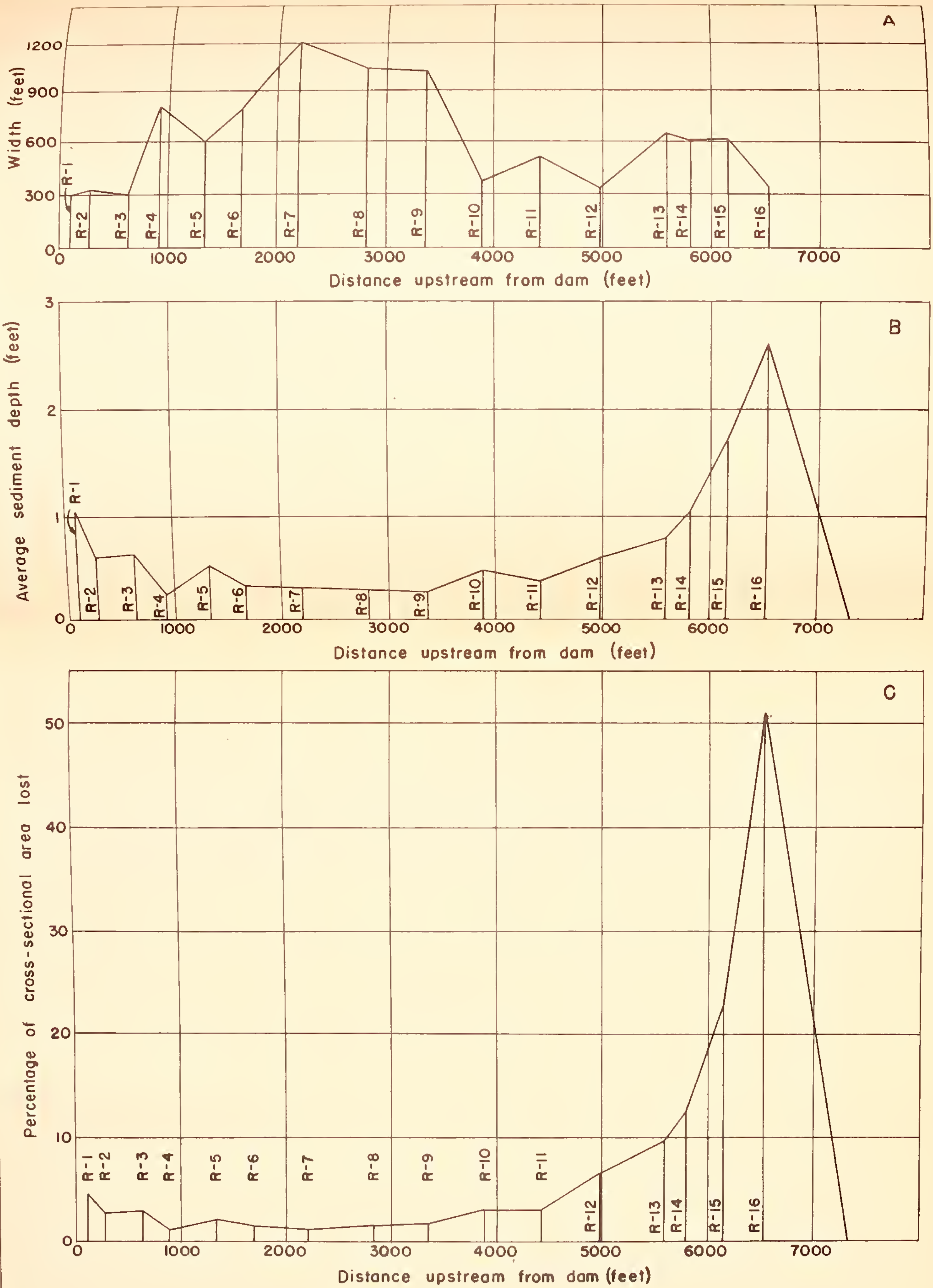

Figure 10-Sediment range characteristics, Lake Issaqueena, Pickens County, South Carolina

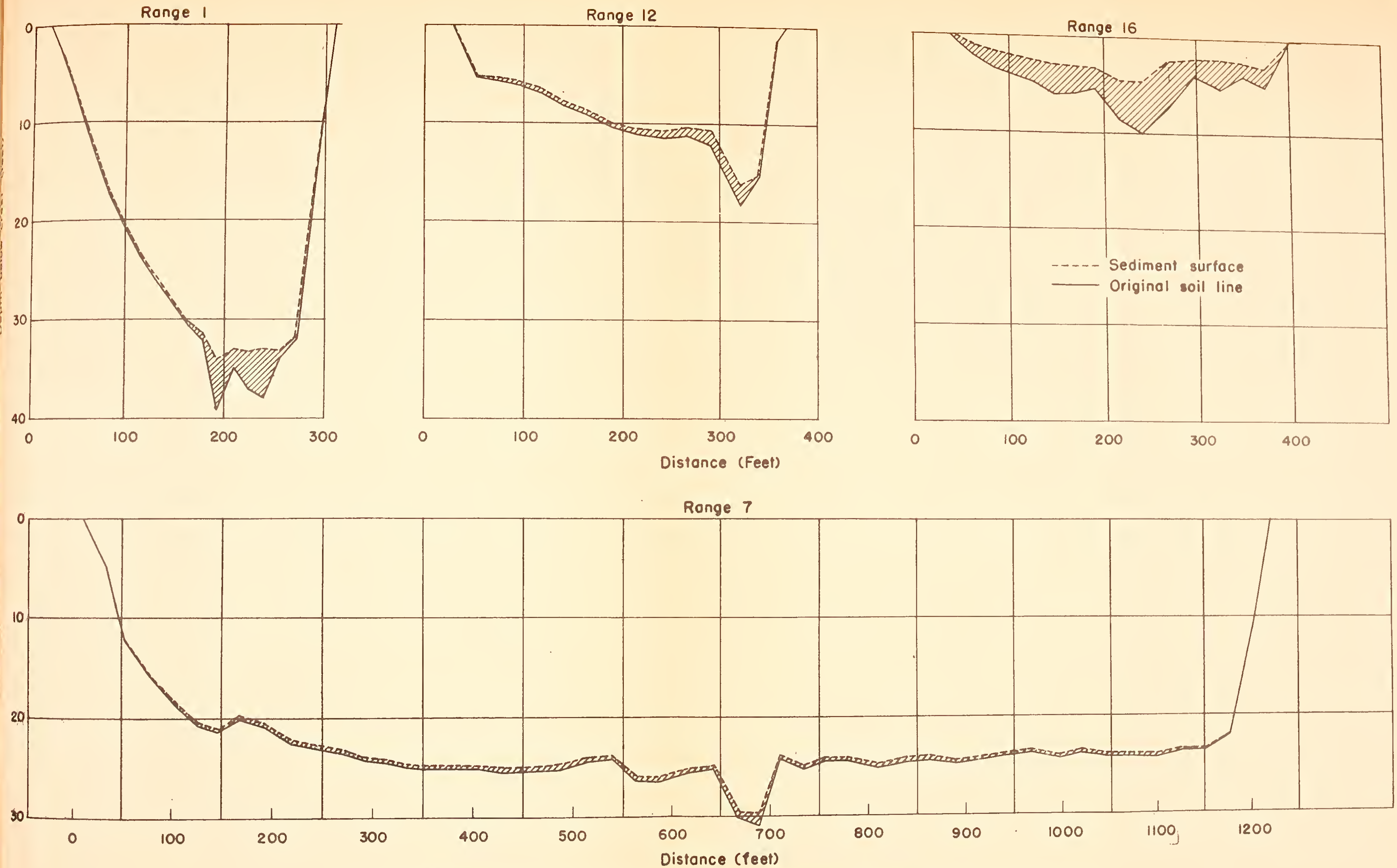

Figure 11.–Representative sediment ranges, Lake Issaqueena, Pickens County, South Carolina

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Table 7.--Cross-section data in Lake Issaqueena, S. C.

Range	Width	Area		Average water depth		Sediment	
		Original	1941	Original	1941	Area	Average depth
	Feet	Square feet	Square feet	Feet	Feet	Square feet	Feet
1....................	293	6,934	6,624	23.67	22.61	310	1.06
2....................	312	7,450	7,258	23.88	23.26	192	.62
3....................	308	6,775	6,570	22.00	21.33	205	.67
4....................	806	17,941	17,726	22.26	21.99	215	.27
5....................	606	15,493	15,157	25.57	25.01	336	.55
6....................	791	17,698	17,417	22.37	22.02	281	.36
7....................	1,212	27,749	27,376	22.90	22.59	373	.31
8....................	1,037	20,835	20,521	20.09	19.79	314	.30
9....................	1,022	17,202	16,902	16.83	16.54	300	.29
10....................	365	5,701	5,519	15.62	15.12	182	.50
11....................	533	6,374	6,173	11.96	11.58	201	.38
12....................	340	3,171	2,962	9.33	8.71	209	.61
13....................	655	5,558	5,025	8.49	7.67	533	.81
14....................	602	5,011	4,381	8.32	7.28	630	1.05
15....................	611	4,499	3,454	7.36	5.65	1,045	1.71
16....................	362	1,850	903	5.11	2.49	947	2.62
17....................	167	1,612	1,602	9.65	9.59	10	.06
18....................	343	3,232	3,149	9.42	9.18	83	.24
19....................	622	5,128	4,710	8.24	7.57	418	.67
20....................	342	1,721	1,156	5.03	3.38	565	1.65

SUSPENDED-MATTER OBSERVATIONS

Measurement of the suspended load of typical Piedmont streams (6, 8) shows that the load consists very largely of fine material. Because the finer grades of sediment are carried in so much greater quantities than the coarser grades, they are normally more important in contributing to the deposits in reservoirs constructed on these streams.

The coarse material may constitute only a relatively small percentage of the total sediment load in a stream, but all of it will deposit as a delta at the head of a reservoir. The fine material, on the other hand, may not deposit completely and some of it may pass through the reservoir either by general mixing and subsequent flow over or through the dam, or by passing along the bottom as a density current. In either case, however, it may be possible under some conditions to pass an appreciable amount of fine material through a reservoir by operation of properly located outlet gates, whereas little or nothing can be done economically to remove the delta deposits of coarse material.

The phenomenon of underflow in a reservoir occurs where the heavier, sediment-laden water of the inflowing stream flows under the lighter desilted waters already in storage. The higher density of the underflow current may be due not only to suspended matter, but also to dissolved matter or temperature or to any combination of these factors.

During a flood, the lake water in some reservoirs, where conditions favoring underflow are not present, may become thoroughly mixed with the inflowing sediment-laden stream water and is then turbid in appearance throughout the length and depth of the reservoir; later the sediment slowly settles. Eventually all material (except unflocculated colloids) reaches the bottom and the water becomes relatively clear, provided conditions are not altered by subsequent floods.

The venting of sediment-laden water from a reservoir can be controlled to a certain degree by the proper operation of gates, located in the dam. To obtain information on this problem, investigations extending over a period of several years were made by the Sedimentation Division of the Soil Conservation Service. Important among these investigations have been the laboratory studies in cooperation with the California Institute of Technology, Pasadena, that have demonstrated the general principles underlying the problem (1). To apply these principles in the development of methods by which density currents could be utilized to vent sediment from an actual reservoir, investigations were made at Lake Issaqueena near Clemson, South Carolina, by the staff of the Sedimentation Division's sediment-load laboratory near Greenville, South Carolina (2).

Lake Issaqueena was selected for these investigations because published statements (9) had indicated that sediment-laden underflows occurred in this lake on certain occasions. In an attempt to provide data for correlating the laboratory experiments with field conditions certain preliminary investigations were conducted in Lake Issaqueena. These observations are discussed below.

Collection of Data

The investigation at Lake Issaqueena was intended primarily to yield information on (1) the frequency of occurrence of underflows in the lake, and (2) the general magnitude of the volume of sediment that could be passed through the reservoir by a simple and inexpensive plan of outlet gate operation.

In connection with the first phase of the problem it was reasoned that by permitting the normal outflow from the reservoir to pass through the gates, located near the base of the dam, the passage of an underflow through the reservoir, following a rise on the inflowing stream (which is normally clear, but turbid during floods), could be detected by frequent sampling of the water discharged from the gates. If, shortly after a rise occurred, the suspended-matter concentration in the water discharged through the gates showed a decided increase, with little or no change in the concentration of the surface water, then an underflow of sediment-laden water surely must have passed through the reservoir.

Of the two openings located in the dam (see fig. 3), one 30-inch pipe and one 24-inch pipe, only the 24-inch pipe was permitted to received flow during the investigation. The gate that controlled this opening was adjusted to discharge the low-water outflow so that little or no water passed over the spillway except during floods. Dip samples of water for determination of suspended-matter concentration were obtained in pint milk bottles at the lake surface and at the outlet from the gate (see table 8). The first samples were taken on May 8, 1940, but on October 31, 1940, regular sampling was started and continued at weekly intervals until April 23, 1942, with the exception of the months of March, June, July and October, 1941.

On several occasions, the vertical distributions of suspended-matter concentration and temperature in the lake were also measured (see table 9). These measurements were based on individual samples collected at various depths. The normal procedure of sampling was to lower an air-filled pint milk bottle, held in a special holder, to the desired depth by means of a marked sounding line, and then to remove a one-half inch diameter plug in the rubber stopper of the bottle by pulling an auxiliary line. When filled, the bottle was pulled quickly from the lake and the temperature of the sample obtained with an ordinary laboratory thermometer.

Most of the verticals were taken from a platform upon which the gate-lifting mechanisms are located on the upstream side of the dam. On several occasions verticals were taken at various points throughout the length of the lake from a boat (7), (figs. 12, A and B).

An automatic stage recorder was installed on Six Mile Creek, the main inflowing stream, above a gravel shoal approximately 200 feet upstream from the bridge near the upper end of the lake. This recorder was installed primarily to give a record of the maximum stage and its time of occurrence during each rise. A stage recorder also was installed at the dam to give information on the changes in water-surface elevation in the lake. Unfortunately, arrangements could not be made to sample the inflowing streams with sufficient frequency during floods to permit an estimate to be made of the sediment load entering the reservoir. However, it is believed that the various vertical distributions of sediment concentration, as measured after a stream rise, if used in connection with a reservoir capacity curve, permit an accurate estimate of the sediment in suspension in the lake. Precipitation records were obtained from a recording rain gage (No. SCS-17) located at Clemson, S. C., approximately six miles from the dam.

Summary of Data

Figures 12 and 13 summarize much of the basic data obtained from the suspended-matter observations at Lake Issaqueena. These data include the daily rainfall, stage of the main inflowing stream, discharge from the outlet, and suspended-matter concentration. Figure 12 shows examples of the vertical distribution of suspended-matter concentration and temperature at various dates and at various locations in the lake (7).

Examination of the curves of suspended-matter concentration (fig. 13) shows that on nine occasions the concentration in the water discharged from the outlet increased considerably without an appreciable change in the concentration of the surface waters. Immediately preceeding these periods, a significant rainfall and a resulting rise in the stage of the inflowing stream was observed. Unquestionably, underflows of sediment-laden water passed through the reservoir on these nine occasions. In all cases, however, the gate discharge was less than the discharge of the underflow, and, as shown by the vertical distributions of sediment concentration, a pool of turbid water formed in the lowest part of the reservoir. Sediment in suspension in the pool either settled to the bottom or was drawn out through the gate. Withdrawal of as much as possible of the sediment in suspension in a pool before it settles to the bottom requires a high gate discharge. At certain depths of the pool it is possible that if the discharge is too great, clearer water from above will be drawn through the gate; however, if conservation of storage capacity is more important than the conservation of clear water, the discharge that will permit the greatest amount of sediment to be vented in the shortest time should be used.

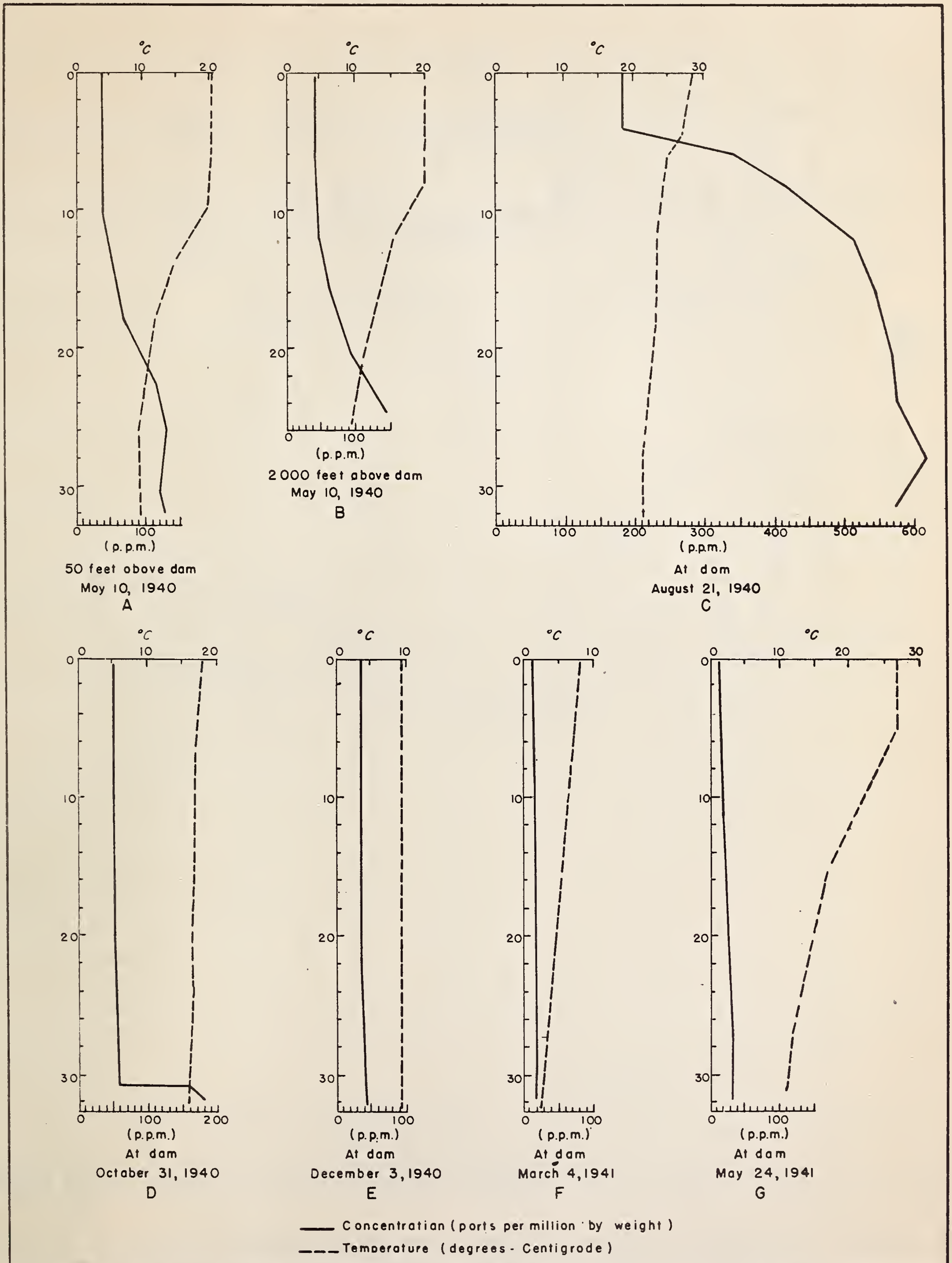


Figure 12.—Vertical distribution of suspended-matter concentration and temperature in Lake Issaqueena, Clemson, S.C.

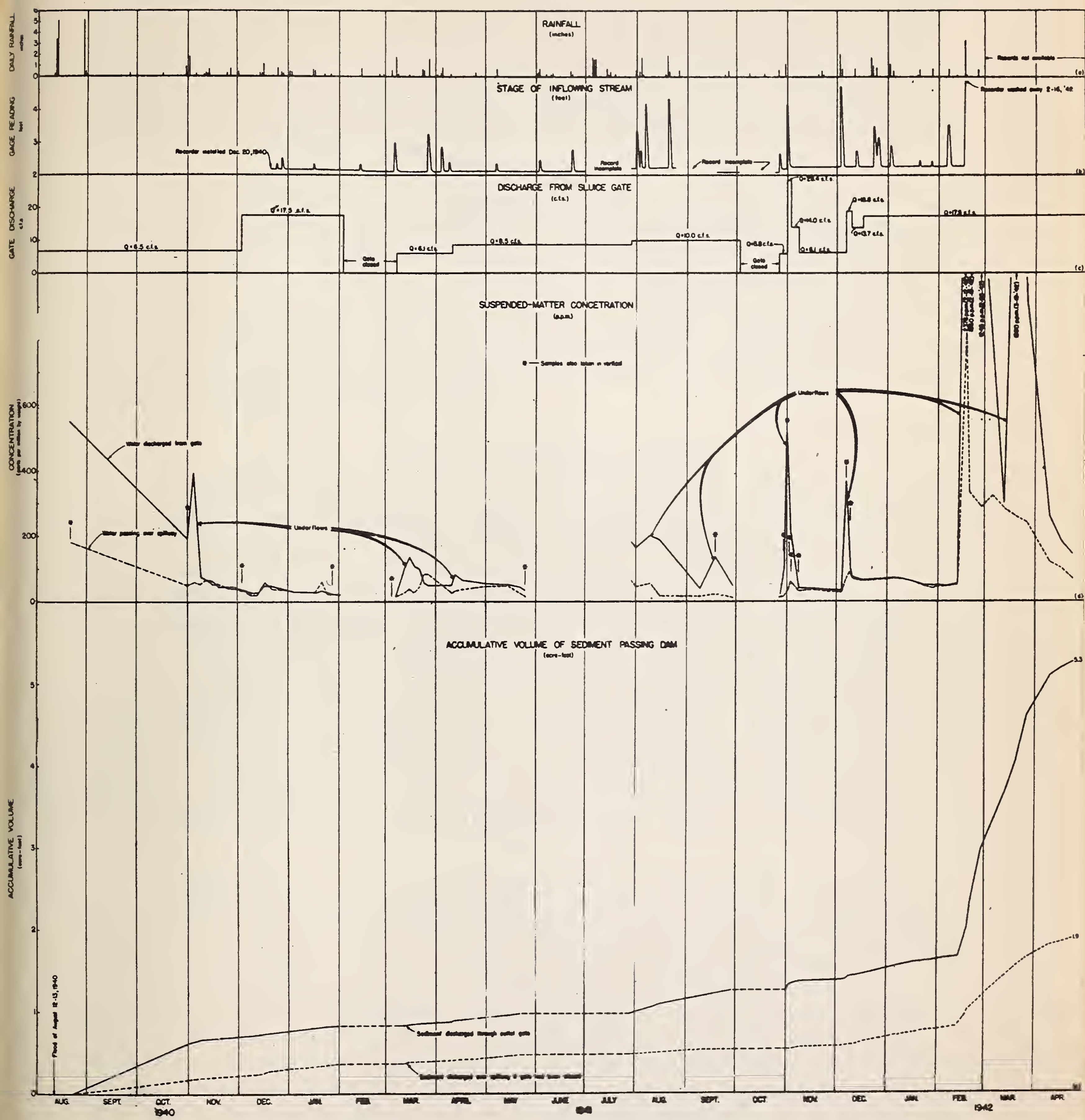


Figure 13.—Results of suspended-matter sampling in Lake Issaqueena, Clemson, S. C.

The data in figure 13 are of importance primarily in showing that underflows pass through Lake Issaqueena after almost every appreciable rise on the main inflowing stream. To obtain more complete information on the individual underflows than that given by figure 13 would require a much more elaborate sampling program than was used in the present investigation, because the suspended matter in water discharged through the gate comes from the turbid pool and may contain material from several underflows.

After the underflow of March 1941, the suspended-matter concentration of the surface waters started to increase, reached a peak concentration that was greater than that of the water being discharged from the sluice gate, and then receded. A possible explanation of this phenomenon is that an overflow of sediment-laden water occurred. This overflow probably was caused by water of relatively high temperature flowing over the cooler underlying lake waters and carrying with it any suspended matter resulting from general mixing at the head of the lake during the previous stream rise.

Quantity of Sediment Vented

In August 1940 exceptionally heavy rains resulted from a hurricane that swept the South Atlantic States. Precipitation of 3.44 inches on August 12 and 5.14 inches on August 13 were recorded on the Clemson gage. As a result, a near-record flood occurred on Six Mile Creek with a discharge of approximately 1,580 cubic feet per second passing over the spillway of the Lake Issaqueena Dam. A vertical distribution of sediment concentration measured on August 21, a few days after the flood (fig. 12-C) indicated that because of the relatively large inflow either a general mixing between inflow water and lake water occurred and extended completely down the lake to the dam (6), or a complete change of water in the lake had taken place. On October 31, more than two months later, a second vertical distribution of sediment concentration was measured (fig.12-D) and showed that the only water of high-sediment concentration remaining in the reservoir was a relatively thin layer approximately 2 feet thick along the bottom.

During the period between August 21 and October 31, the gate was adjusted to discharge the low-water outflow from the reservoir so that little or no water passed over the spillway. Sediment distributed throughout the body of the reservoir by general mixing during the flood was greatly reduced in quantity during the intervening period by settlement and by discharging water containing high-sediment concentrations from the outlet. Thus, by computations, using the vertical distribution of sediment concentration and the capacity curve of the reservoir, it was estimated that 975 tons of sediment were in suspension in the lake on August 21, but on October 31 only 120 tons remained. The difference, 855 tons, either settled or passed through the sluice gate. It was estimated from the records of the gate discharge and concentration in the water that 148 tons, or 17 percent of this sediment had passed through the gate. Although this amount was not large, it is important to note that a much larger quantity could have been vented had the discharge

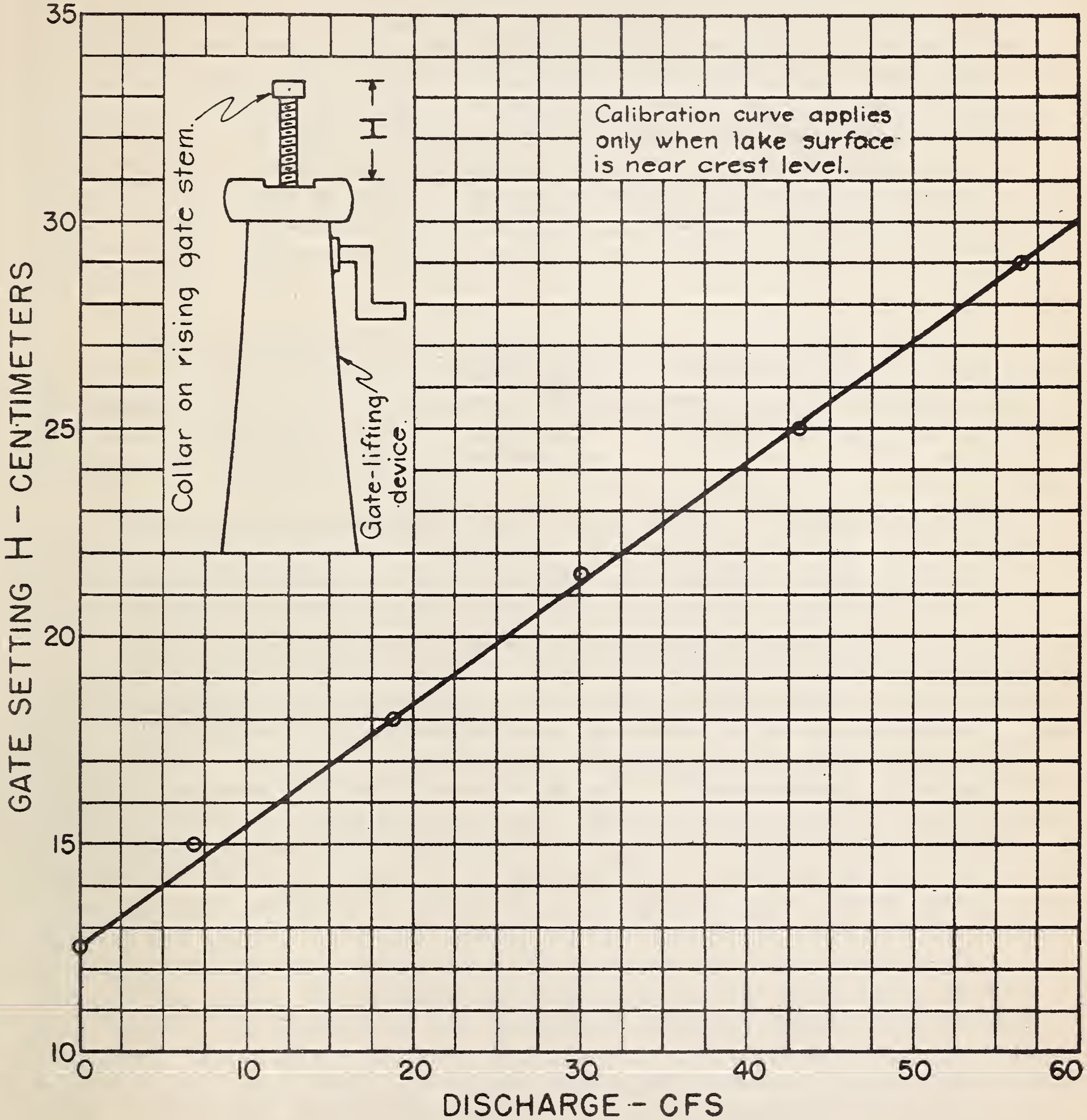
through the gates been controlled for this particular purpose. That is, instead of a discharge of only 6.5 cubic feet per second from one gate, discharges up to the maximum capacity of both gates (approximately 250 cubic feet per second) could have been used for short periods following floods to vent a large volume of water from the pool in a relatively short time.

In an attempt to obtain detailed information on the efficiency of venting the sediment transported through Lake Issaqueena by an underflow, a program of sampling and gate operation was carried out during the period October 27 to November 3, 1941, when two underflows passed through the lake. These observations included a record of the stage of the main inflowing stream, the lake level at the dam, suspended-matter concentration in the surface water and of the water discharged through the gate. A few observations of suspended-matter concentration in the inflowing stream also were made. From a record of the gate setting, the discharge through the gate was obtained from a calibration curve (fig. 14). To obtain information on the extent and sediment content of the pool of highly turbid water then existing in the lower part of the reservoir, several observations on the vertical distribution of suspended-matter concentration also were made at various points throughout the length of the lake.

Following a rain of 0.55 inch, as recorded on the Clemson gage on October 27, a rise in stage was observed on the main stream flowing into Lake Issaqueena. A few samples of the inflow were taken and showed a maximum sediment concentration of 590 parts per million. This turbid water entered the head of the lake at 6:00 p.m. on that day. Samples of water taken on the following day failed to indicate that any underflow had reached the dam. No sample was taken on October 29, but a sample taken on October 30 showed that the sediment concentration in the sluice-gate discharge had increased from 20 to 90 parts per million while the surface concentration remained unchanged. From the vertical distribution of suspended-matter concentration measured on October 30 it appears that the underflow was ponded in the lowest part of the reservoir to a depth of approximately 11 feet. From a consideration of the length of the lake and the time elapsed between samples, it appears that the underflow passed through the lake at a velocity of about 0.10 foot per second, or possibly less.

During the night of October 31, rain amounting to 1.30 inches fell and another rise of stage was observed on Six Mile Creek. Only a few samples of the inflow were obtained and these were taken several hours after the maximum discharge (and no doubt the maximum suspended-matter concentration) had occurred. The maximum concentration in these samples, however, was 1,071 parts per million. (A mechanical analysis curve of a composite sample of all samples taken on Six Mile Creek is shown in figure 9.)

Observations on the suspended-matter concentration in the surface water, the water discharged from the gate, and in several verticals were made on the days immediately following - namely, November 1, 2, and 3.



CALIBRATION CURVE FOR 24-INCH OUTLET PIPE IN LAKE ISSAQUEENA DAM

The maximum observed concentration of suspended matter in the discharge through the gate was 504 parts per million and was obtained on November 1. A vertical distribution of sediment concentration on this date shows that a pool approximately 7 feet in depth then occupied the lower part of the reservoir. As shown in figure 13 the discharge through the sluice gate was increased from 5.8 cfs to 13.0 cfs and then further increased to 28.4 cfs in an effort to draw out most of the water from this turbid pool. Apparently the flow into this pool exceeded even this increased outflow because a measurement made on the following day (November 2) showed that the depth of the pool of turbid water had increased to approximately 11 feet. Observations taken at various points throughout the length of the lake on this date showed that the upper surface of the pool was approximately level, indicating that a static equilibrium condition apparently had been reached.

The discharge from the sluice gate was permitted to remain at 28.4 cfs, and on the following day (November 3) another vertical distribution of suspended matter was obtained. This showed that the depth of the pool had decreased to 9 feet, and that the maximum concentration had decreased to only 175 parts per million.

These various observations are of value in demonstrating the effectiveness of a plan of controlled regulation in venting suspended matter from a reservoir. For example, on November 2 when sampling showed that the pool of turbid water had reached a condition of equilibrium, it was estimated from the vertical distribution of concentration and the reservoir-capacity curve that 166 tons of suspended sediment were in the entire lake, 43 tons of which were in the turbid pool. However, on the following day (November 3) it was estimated that 126 tons of sediment were in suspension in the entire lake with only 18 tons remaining in the turbid pool. Thus 40 tons of sediment were no longer in suspension but had either settled to the bottom or had been withdrawn with the water discharged through the gate. From the gate discharge and the suspended-matter concentration in these waters it was estimated that 18 tons of sediment were discharged through the gate. In other words, of the amount of sediment no longer in suspension in the entire lake, 45 percent had been discharged through the gate. Of perhaps more interest is the fact that, in the pool itself, 72 percent of the suspended sediment passed out through the gate. By keeping the gate discharge at 28.4 cfs most of the water in the turbid pool could have been withdrawn; however, to prevent too great a drawdown in the lake level, the gate discharge was reduced to 15.5 cfs at 10:25 a.m. and then to 14.4 cfs at 1:50 p.m. on November 3. Samples for suspended-matter concentration taken from the gate discharge 5 days later (November 8) showed that the concentration then had dropped to about 40 parts per million.

Another record of venting sediment begins with the formation of a turbid pool in Lake Issaqueena in the early part of December 1941. The runoff from rains of 2.06 inches on December 3 and 0.63 inches on December 4 passed through the lake as an underflow (fig. 13-D). From vertical distributions of concentration taken on December 7 and again on December 9, and from the record of gate discharge and concentration of these waters, it was estimated that during this two-day period 79 percent of the suspended sediment lost from the pool was vented through the gate.

Information on the amount of sediment that was vented from the reservoir during the entire period of record was computed from the suspended-matter concentration (fig. 13-D) and the gate discharge (fig. 13-C). Starting with the sample taken on August 21, the accumulated load for the whole period of sampling was computed and then converted to volume by assuming a unit weight of deposited sediment of 35 pounds per cubic foot, this being the average value for samples of sediment taken near the dam. This accumulated volume of sediment passed through the gate is summarized in figure 13-D. Also shown in this figure is the accumulated volume of sediment that would have been carried over the spillway, if the gate had been closed and the amount of water that passed through the gate had been forced instead to flow over the spillway as water of the low sediment concentration existing at the lake surface.

The difference between the two accumulative curves (fig. 13E) gives the volume of sediment that operation of the gate prevented from depositing in the lake between August 21, 1940, and any subsequent date. For instance, between August 21, 1940, and April 23, 1942, a total of 5.3 acre-feet of sediment was passed through the gate. If the gate had been closed completely, approximately 1.9 acre-feet would have been passed over the spillway anyway. The net effect of operating the gate during the period of record was to vent 3.4 acre-feet of sediment which otherwise would have settled in the reservoir. Of this total amount, however, the greatest portion was vented during the three-month period following the flood of August 12-13, 1940, and during the periods immediately following the underflows that occurred in November and December 1941 and in February and March 1942. As previously mentioned, the amount of sediment vented through the gate no doubt could have been many times that actually passed had the gate operation been more closely controlled at all times.

Conclusions from Suspended-Matter Observations

The investigation at Lake Issaqueena shows that underflows of sediment-laden water frequently passed through the lake and clearly demonstrates the desirability of wasting water of high sediment content through outlet gates near the base of the dam. Such turbid water is often present in the lower part of the storage space either because of general settling of sediment or because of an underflow. The practice of venting muddy water has the two-fold advantage of reducing the silting rate in the reservoir by withdrawing sediment before it can deposit, as well as of permitting the relatively clear surface waters to remain in storage and thus improving the recreational value of the lake.

The mechanics of the flow of turbid water through the lake is of importance in the study of stratified flow in reservoirs, but, whether it mixes with the reservoir water or passes through as an underflow, ordinarily is of little interest to a reservoir operator. His problem is primarily one of operation in which a quick and convenient method, possibly with the aid of a turbidimeter, must be utilized to permit estimates to be made of the nature and extent of the turbid pool in order that the maximum sediment can be vented with a minimum drawdown in the reservoir level.

At any particular time the gate discharge that can be used effectively depends on the depth of the turbid pool, the density difference, the bottom slope, and the permissible drawdown. In a recreational lake it is desirable that the water should appear clear; therefore, the discharge through the sluice gate should not be great enough to draw relatively clear water from that part of the lake above the turbid pool. When there is a choice of conserving clear water or conserving storage space, however, the conservation of storage by venting as much sediment as possible usually should govern. Therefore, within the limits of permissible drawdown, but irrespecitve of any loss of clear water, a gate discharge should be used that will permit the maximum amount of sediment to be vented from the reservoir. For maximum efficiency in venting muddy water several groups of small gates, possibly located at various levels, are preferable to a single large opening. The most effective design and location of gates and the method of operating them for best results, however, is not yet known in detail and must be determined by further investigation and experience.

Table 8.--Suspended-matter observations in water discharged from Lake Issaqueena

Date	Hour	Sampling point: Lake surface: Concentration	Sampling point: Lake surface: Temperature	Sampling point: Sluice gate: Concentration	Sampling point: Sluice gate: Temperature	Sluice-gate discharge
		Parts per million	°C	Parts per million	°C	Second-feet
1940						
May:						
8........	4:15 p.m.	44	----	141	----	6.5
9........	11:30 a.m.	42	----	127	----	6.5
10........	12:15 p.m.	44	----	127	----	6.5
August:						
21.......	1:00 p.m.	183	28.6	552	21.2	6.5
October:						
31.......	12:30 p.m.	52	17.5	194	16.0	6.5
November:						
4........	4:45 p.m.	60	----	396	----	6.5
8........	10:30 a.m.	52	----	74	----	6.5
12.......	3:00 p.m.	70	----	65	----	6.5
16.......	9:00 a.m.	52	----	60	----	6.5
20.......	10:00 a.m.	54	----	42	----	6.5
23.......	4:00 p.m.	43	----	44	----	6.5
25.......	4:00 p.m.	44	----	40	----	6.5
29.......	10:00 a.m.	48	----	41	----	6.5
December:						
3........	10:45 a.m.	33	9.6	37	9.3	6.5
5........	11:15 a.m.	33	10.3	35	9.5	17.5
6........	10:30 a.m.	28	----	32	----	17.5
9........	8:00 a.m.	20	----	25	----	17.5
13.......	4:00 p.m.	20	----	26	----	17.5
17.......	3:00 p.m.	60	----	50	----	17.5
21.......	10.00 a.m.	40	----	50	----	17.5
29.......	3.45 p.m.	34	----	36	----	17.5
1941						
January:						
3........	9:00 a.m.	30	----	31	----	17.5
7........	1:00 p.m.	29	----	31	----	17.5
10.......	2:00 p.m.	27	----	27	----	17.5
13.......	2:00 p.m.	27	----	27	----	17.5
17.......	10:00 a.m.	32	----	27	----	17.5
21.......	4:00 p.m.	61	----	33	----	17.5

Table 8.--Continued

Date	Hour	Sampling point: Lake surface: Concentration (Parts per million)	Lake surface: Temperature (°C)	Sluice gate: Concentration (Parts per million)	Sluice gate: Temperature (°C)	Sluice-gate discharge (Second-feet)
1941						
January:						
24........	11:00 a.m.	24	----	28	----	17.5
28........	10:15 a.m.	22	----	21	----	17.5
February:						
1........	2:00 p.m.	24	----	21	----	17.5
March						
4........	1:45 p.m.	14	8.5	Gate closed		0.0
7........	11:30 a.m.	14	----	14	----	6.1
12........	2:30 p.m.	26	----	98	----	6.1
15........	2:00 p.m.	41	----	137	----	6.1
18........	4:00 p.m.	26	----	108	----	6.1
21........	3:00 p.m.	45	----	100	----	6.1
24........	4:30 p.m.	85	----	57	----	6.1
27........	4:45 p.m.	84	----	49	----	6.1
April:						
10........	1:30 p.m.	26	----	49	----	8.5
12........	11:00 a.m.	34	----	84	----	8.5
17........	3:15 p.m.	36	----	67	----	8.5
28........	12:30 p.m.	43	----	56	----	8.5
May:						
14........	10:00 a.m.	49	----	51	----	8.5
22........	9:00 a.m.	22	----	43	----	8.5
24........	11:00 a.m.	14	27.0	34	11.0	8.5
July:						
29........	1:45 p.m.	63	30.5	182	18.0	10.0
August:						
1........	12:00 p.m.	46	32.0	164	18.0	10.0
9........	4:00 p.m.	55	----	200	----	10.0
16........	3:00 p.m.	--	----	138	----	10.0
September:						
9........	2:00 p.m.	15	----	37	----	10.0
13........	2:00 p.m.	23	28.0	134	21.5	10.0
29........	4:00 p.m.	13	----	46	----	10.0
October:						
27........	1:45 p.m.	12	20.5	27	19.5	5.8
28........	1:00 p.m.	12	----	20	----	5.8

Table 8.--Continued

Date	Hour	Sampling point: Lake surface: Concentration	Lake surface: Temperature	Sluice gate: Concentration	Sluice gate: Temperature	Sluice-gate discharge
		Parts per million	°C	Parts per million	°C	Second-feet
1941						
October:						
30........	10:30 a.m.	--	----	90	19.0	5.8
November:						
1.........	3:00 p.m.	27	19.5	504	18.0	5.8
2.........	3:30 p.m.	38	19.0	379	18.1	28.4
3.........	10:15 a.m.	61	18.0	205	17.8	28.4
8.........	11:45 a.m.	31	16.6	40	16.2	14.0
18........	12:45 p.m.	34	----	36	----	6.1
26........	2:30 p.m.	29	----	32	----	6.1
December:						
4.........	12:00 p.m.	27	----	30	----	6.1
7.........	5:30 p.m.	71	11.0	362	12.0	18.8
9.........	11:00 a.m.	89	10.0	88	10.0	18.8
10........	2:30 p.m.	72	----	72	----	13.7
12........	3:15 p.m.	66	----	71	----	13.7
16........	3:50 p.m.	61	----	64	----	17.5
1942						
January:						
5.........	10:30 a.m.	72	----	71	----	17.5
9.........	3:30 p.m.	67	----	69	----	17.5
16........	3:30 p.m.	58	----	58	----	17.5
23........	4:00 p.m.	46	----	48	----	17.5
28........	12:45 p.m.	40	----	48	----	17.5
30........	2:15 p.m.	44	----	49	----	17.5
February:						
5.........	3:40 p.m.	45	----	44	----	17.5
12........	3:40 p.m.	50	----	52	----	17.5
17........	7:20 p.m.	813	----	2,376	----	17.5
19........	7:15 p.m.	332	----	1,860	----	17.5
26........	3:30 p.m.	238	----	1,345	----	17.5
March:						
5.........	4:30 p.m.	320	----	---	----	17.5
12........	4:15 p.m.	284	----	298	----	17.5
19........	4:00 p.m.	260	----	1,590	----	17.5
26........	4:00 p.m.	241	----	898	----	17.5
April:						
9.........	3:15 p.m.	119	----	259	----	17.5
16........	3:00 p.m.	100	----	180	----	17.5
23........	11:50 a.m.	69	----	142	----	17.5

Table 9.--Vertical distribution of suspended matter and temperature in Lake Issaqueena

Sampling date and hour	Gage[1] height	Depth[2] below lake surface	Concentration	Temperature	Location of vertical
	Feet	Feet	Parts per million	°C	
May 10, 1940					
12:15 p.m.	2.00	0	44	----	50 feet above dam
1:42 p.m.	2.00	2	38	20.2	do
1:48 p.m.	2.00	6	39	20.1	do
1:53 p.m.	2.00	10	39	19.8	do
1:58 p.m.	2.00	14	55	14.3	do
2:02 p.m.	2.00	18	70	11.6	do
2:07 p.m.	2.00	22	111	10.2	do
2:12 p.m.	2.00	26	131	9.4	do
2:19 p.m.	2.00	30	118	9.5	do
2:25 p.m.	2.00	32	122	9.2	do
2:31 p.m.	2.00	33.5 (Bed)	125	9.0	do
May 10, 1940					
3:37 p.m.	2.00	0	39	20.0	2,000' above dam
3:41 p.m.	2.00	4	44	20.0	do
3:45 p.m.	2.00	8	45	20.0	do
3:49 p.m.	2.00	12	48	15.2	do
3:52 p.m.	2.00	16	59	13.3	do
3:58 p.m.	2.00	20	89	11.0	do
4.02 p.m.	2.00	24	133	9.8	do
4:06 p.m.	2.00	26.2 (Bed)	—	9.8	do
Aug. 21, 1940					
1:22 p.m.	2.00	1	183	28.6	At dam
1:18 p.m.	2.00	4	182	26.8	do
1:27 p.m.	2.00	6	345	24.8	do
1:15 p.m.	2.00	8	411	24.0	do
1:11 p.m.	2.00	12	510	23.0	do
1:08 p.m.	2.00	16	546	22.9	do
1:04 p.m.	2.00	20	564	22.4	do
1:01 p.m.	2.00	24	574	21.9	do
12:55 p.m.	2.00	28	616	20.8	do
12:50 p.m.	2.00	32 (Bed)	571	21.2	do

[1] Gage height of spillway crest = 2.00

[2] Intake of water sampler was 0.71 foot above nominal depth. Except for surface samples, subtract this from recorded depth to obtain true depth.

Table 9.--Continued

Sampling date and hour	Gage[1] height	Depth[2] below lake surface	Concen- tration	Temper- ature	Location of ver- tical
	Feet	Feet	Parts per million	°C	
Oct. 31, 1940					
12:27 p.m.	2.00	0	52	17.5	At dam
12:23 p.m.	2.00	4	72	17.2	do
12:20 p.m.	2.00	8	53	17.0	do
12:15 p.m.	2.00	12	51	17.0	do
12:12 p.m.	2.00	16	49	17.0	do
12:07 p.m.	2.00	20	53	16.5	do
12:02 p.m.	2.00	24	48	16.5	do
11:53 p.m.	2.00	28	46	16.3	do
12.51 p.m.	2.00	30	55	16.2	do
1:01 p.m.	2.00	31.3	153	16.0	do
11:46 p.m.	2.00	32 (Bed)	173	16.0	do
Dec. 3, 1940					
10:40 a.m.	2.00	0	33	9.6	At dam
10:37 a.m.	2.00	5	35	9.6	do
10:35 a.m.	2.00	9	36	9.6	do
10.32 a.m.	2.00	13	35	9.6	do
10:29 a.m.	2.00	17	20	9.7	do
10:25 a.m.	2.00	21	37	9.8	do
10:23 a.m.	2.00	25	34	9.7	do
10:18 a.m.	2.00	29	37	9.5	do
10:10 a.m.	2.00	33 (Bed)	44	9.5	do
Jan. 28, 1941					
10:12 a.m.	0.40	0	22	----	At dam
10:10 a.m.	.40	15	23	----	do
10:00 a.m.	.40	27	23	----	do
10:00 a.m.	.40	32 (Bed)	21	----	do
Mar. 4, 1941					
1:42 p.m.	2.04	0	14	8.5	At dam
1:38 p.m.	2.04	32 (Bed)	19	2.5	do
May 24, 1941					
10:54 a.m.	2.00	0	14	27.0	At dam
10:50 a.m.	2.00	5	--	27.0	do
10:45 a.m.	2.00	10	--	22.0	do
10:40 a.m.	2.00	15	22	17.0	do
10:37 a.m.	2.00	27	33	12.0	do
10:30 a.m.	2.00	33.5 (Bed)	35	11.0	do

Table 9.--Continued

Sampling date and hour	Gage[1] height	Depth[2] below lake surface	Concen- tration	Temper- ature	Location of ver- tical
	Feet	Feet	Parts per million	°C	
July 29, 1941					
1:45 p.m.	2.00	0	63	30.5	At dam
1:42 p.m.	2.00	5	62	28.5	do
1:38 p.m.	2.00	10	105	25.5	do
1:35 p.m.	2.00	15	178	23.5	do
1:33 p.m.	2.00	22	160	21.0	do
1:25 p.m.	2.00	27	137	19.5	do
1:20 p.m.	2.00	33 (Bed)	189	18.5	do
Sept. 18, 1941					
2:40 p.m.	1.52	0	23	28.0	At dam
3:00 p.m.	1.52	10	--	27.0	do
3:05 p.m.	1.52	15	32	25.5	do
2:55 p.m.	1.52	20	105	24.0	do
2:50 p.m.	1.52	27.5	--	22.5	do
2:45 p.m.	1.52	33 (Bed)	146	21.5	do
Oct. 30, 1941					
10:10 a.m.	1.94	0	19	19.0	At dam
10:10 a.m.	1.94	23	19	19.0	do
10:15 a.m.	1.94	25.5	80	19.0	do
10:05 a.m.	1.94	28	105	19.0	do
10:03 a.m.	1.94	33 (Bed)	94	18.5	do
Nov. 1, 1941					
3:05 p.m.	2.40	0	27	19.5	At dam
--		15	--	18.0	do
2:50 p.m.	2.40	28	50	18.0	do
3:00 p.m.	2.40	30	217	18.0	do
2:47 p.m.	2.40	31	481	18.0	do
2:42 p.m.	2.40	34 (Bed)	518	18.0	do
Nov. 2, 1941					
3:25 p.m.	1.80	0	38	19.0	At dam
3:12 p.m.	1.80	23	74	18.5	do
3:21 p.m.	1.80	24	222	18.5	do
3:15 p.m.	1.80	25	282	18.5	do
3:09 p.m.	1.80	28	339	18.5	do
3:05 p.m.	1.80	33 (Bed)	446	18.1	do

Table 9.--Continued

Sampling date and hour	Gage[1] height	Depth[3] below lake surface	Concen- tration	Temper- ature	Location of ver- tical
	Feet	Feet	Parts per million	°C	
Nov. 3, 1941					
10:14 a.m.	1.56	0	61	18.0	At dam
10:04 a.m.	1.56	27	100	18.0	do
10:13 a.m.	1.56	28	165	----	do
10:10 a.m.	1.56	29	258	18.0	do
10:01 a.m.	1.56	33 (Bed)	230	17.8	do
Nov. 3, 1941					
1:29 p.m.	1.56	27	86	----	On range R-2
1:26 p.m.	1.56	28	126	----	do
1:32 p.m.	1.56	32.5 (Bed)	195	----	do
Nov. 3, 1941					
10:55 a.m.	1.56	0	44	19.0	On range R-4
10:52 a.m.	1.56	25	50	18.0	do
10.58 a.m.	1.56	27	90	----	do
10:49 a.m.	1.56	28	174	----	do
10:46 a.m.	1.56	32 (Bed)	176	----	do
Nov. 3, 1941					Between ranges
11:40 a.m.	1.56	0	60	----	R-6 and R-7
11:41 a.m.	1.56	20	59	----	do
11:45 a.m.	1.56	23	90	----	do
11:30 a.m.	1.56	25	129	----	do
11:29 a.m.	1.56	26	119	----	do
11:25 a.m.	1.56	27	134	----	do
11:35 a.m.	1.56	30 (Bed)	144	----	do
Nov. 3, 1941					
12.07 p.m.	1.56	0	67	----	On range R-10
12:01 p.m.	1.56	18	83	----	do
12:05 p.m.	1.56	20	80	----	do
12:00 p.m.	1.56	23 (Bed)	81	----	do
Nov. 3, 1941					
12:42 p.m.	1.56	0	72	18.2	On range R-13
12:39 p.m.	1.56	8.5 (Bed)	90	----	do
Nov. 8, 1941					
11:40 a.m.	0.87	0	31	16.6	At dam
11:36 a.m.	.87	15	32	16.5	do

Table 9.--Continued

Sampling date and hour	Gage[1] height	Depth below lake surface	Concentration	Temperature	Location of vertical
	Feet	Feet	Parts per million	°C	
Nov. 8, 1941					
11:33 a.m.	0.87	25	32	16.4	At dam
11:29 a.m.	.87	28	33	16.1	do
11:25 a.m.	.87	30	33	16.1	do
11:20 a.m.	.87	32 (Bed)	55	16.2	do
Dec. 7, 1941					
5:34 p.m.	1.94	0	71	11.0	At dam
5:32 p.m.	1.94	15	78	11.0	do
5:37 p.m.	1.94	20	84	11.0	do
5:41 p.m.	1.94	22	101	11.0	do
5:45 p.m.	1.94	23	194	11.5	do
5:29 p.m.	1.94	25	196	11.5	do
5:24 p.m.	1.94	30	360	12.0	do
5:19 p.m.	1.94	32.5	371	12.0	do
5:15 p.m.	1.94	33.5 (Bed)	376	12.2	do
Dec. 9, 1941					
10:56 a.m.	1.71	0	89	10.0	At dam
10:54 a.m.	1.71	15.0	88	10.0	do
10:52 a.m.	1.71	25.0	90	10.5	do
10:50 a.m.	1.71	33.0 (Bed)	99	10.5	do

Table 10.--Suspended-matter observations in Six Mile Creek at stage recorder above Lake Issaqueena[1]

Time of sampling		Concentration	Time of sampling		Concentration
Date	Hour		Date	Hour	
		Parts per million			Parts per million
1940			1941		
Oct. 31	2:05 p.m.	73	Oct. 27	5:26 p.m.	173
Dec. 3	9:00 a.m.	68	Oct. 27	5:35 p.m.	165
Dec. 6	10:00 a.m.	13	Oct. 27	5:45 p.m.	139
1941			Oct. 28	11:15 a.m.	219
Mar. 4	1:02 p.m.	93	Oct. 28	12:15 p.m.	189
Mar. 7	12:23 p.m.	1,588	Nov. 1	2:02 p.m.	1,071
Aug. 9	5:00 p.m.	20	Nov. 1	3:45 p.m.	734
Aug. 16	3.45 p.m.	17	Nov. 1	4:05 p.m.	702
Oct. 27	3:40 p.m.	25	Nov. 1	4:40 p.m.	634
Oct. 27	4:10 p.m.	34	Nov. 2	4:23 p.m.	71
Oct. 27	4:12 p.m.	590	Nov. 18	1:20 p.m.	25
Oct. 27	4:25 p.m.	490	Nov. 26	3:15 p.m.	12
Oct. 27	4:48 p.m.	448	Dec. 4	12:40 p.m.	3,124
Oct. 27	5:09 p.m.	317	Dec. 7	6:15 p.m.	25

1/ See figure 9 for mechanical analysis of composite sample of above samples.

CONCLUSIONS AND RECOMMENDATIONS

At the time of this survey Lake Issaqueena was only 2.9 years old, but during this period had lost 4.79 percent of its original capacity. The annual rate of depletion of 1.65 percent is far above the average for reservoirs in the Southeastern States. This unusually high rate of sedimentation has been caused, in considerable measure, by the exceptionally heavy rainfall that occurred over the Southeastern States during August 11-13, 1940, and resulted in maximum discharges and flooding on all streams in this section. Six Mile Creek, which is the main source of inflow to Lake Issaqueena, has a normal discharge of approximately 20 second-feet, and this flow is sufficient to maintain the lake surface at spillway crest. The flood that followed the heavy rainfall of August 11-13 resulted in a maximum discharge of 1,580 second-feet passing over the spillway of the Lake Issaqueena Dam. At Clemson College, about 6 miles from the lake, the total rainfall for the month of August 1940 was 14.14 inches, and the rainfall for the period August 11-13 was 8.60 inches. It has been reported (5) that in this section the probable frequency of monthly precipitation of more than 15.25 inches was once in 10 years, and monthly precipitation of more than 12 inches once in 5 years. Therefore, it is obvious that the annual silting rate over a longer period of years would be substantially lower.

Regardless of the above considerations, it appears that the sedimentation rate in Lake Issaqueena will be substantially higher than for most reservoirs of the Piedmont. This is due, in part, to topography and land use in the drainage area as indicated by a comparison of data on other Piedmont drainage areas that have contributed, on the basis of reservoir surveys, appreciably less sediment per square mile annually. The significant difference appears to be the more mature dissection and steeper slopes in the Six Mile Creek watershed, although slightly more land is in cultivation than in the average Piedmont watershed. The greater dissection in this upper part of the Piedmont Plateau is due to its proximity to the Blue Ridge Mountain Front, about 15 miles to the west. The following tabulation shows the decidedly steeper slopes in the area tributary to Lake Issaqueena. The data on these drainages are derived from a detailed study of maps based on detailed compilation from conservation surveys. The figures represent the proportion of the area with slopes greater than 7 percent.

	Percent
Spartanburg Reservoir drainage area	65.7
University Lake drainage area	52.3
Greensboro Reservoir drainage area	65.1
Franklinton Reservoir drainage area	27.7
Lake Michie drainage area	26.7
Lake Issaqueena drainage area	83.9

A survey of the Lake Issaqueena watershed and a bried reconnaissance by the writers have given definite indication that two major sources of reservoir sediment are: Poorly maintained roadside ditches that have caused severe erosion in adjacent farm fields and destroyed large sections of the roads themselves, and unprotected stream banks which, during the high intensity flash floods of the late summer months, are very susceptible to caving and washing. Sheet and gully erosion also have an important part in supplying the streams and creeks with a heavy sediment load. A well rounded erosion control program in this watershed, including road and gully control and stream bank treatment, would materially reduce the sediment load reaching Lake Issaqueena. In addition, it would improve the value and productiveness of the farm lands, as has been widely demonstrated in the Soil Conservation Districts of the State in recent years. Such a program, with its twofold justification in this small area, should be started at the earliest possible date.

The results of suspended-matter observations demonstrate the desirability of wasting water of high-sediment content, commonly found in the lower part of the storage space, either by general settling of sediment or by the occurrence of underflows, through outlet gates near the base of the dam, rather than wasting the relatively clear surface water over the spillway. This practice would have the twofold advantage of reducing the silting rate in the reservoir by withdrawing sediment before it can deposit and of permitting the relatively clear surface waters to remain in storage and thus improve the recreational value of the lake.

The statistical summary, tabulating the quantitative results of the detailed sedimentation survey of Lake Issaqueena, is presented on the following page.

Summary of data on Lake Issaqueena, Clemson, S. C.

	Quantity	Unit
Age 1/	2.9	Years
Watershed area (including area of lake)	14.02	Sq. miles
	8,974	Acres
Watershed area (excluding area of lake)	13.84	Sq. miles
	8,857	Acres
Reservoir:		
Area at spillway stage:		
Original	117	Acres
At date of survey	114	Acres
Storage capacity at crest level:		
Original	1,836	Acre-feet
At date of survey	1,748	Acre-feet
Capacity per sq. mile of drainage area: 2/		
Original	130.96	Acre-feet
At date of survey	124.68	Acre-feet
Sedimentation:		
Total sediment	88	Acre-feet
Bottom-set deposits	46	Acre-feet
Delta deposits	42	Acre-feet
Average annual accumulation:		
From entire drainage area	30.3	Acre-feet
Per 100 sq. miles of drainage area 3/	219	Acre-feet
Per acre of drainage area: 3/		
By volume	149.24	Cubic feet
By weight 4/	3.74	Tons
Depletion of storage:		
Loss of original capacity:		
Per year	1.65	Percent
To date of survey	4.79	Percent

1/ Storage began June 1938; average date of survey April 15, 1941.
2/ Including area of lake.
3/ Excluding area of lake.
4/ Based on dry weights determined from 20 undisturbed samples. Volume weights for the different segments are as follows: Segments 0, 2, 3, 4, 5, 6, 7, 8, 9, 17, and 18, at 35 pounds per cubic foot, segment 10 at 38 pounds, segment 11 at 39 pounds, segments 12 and 13 at 40 pounds, segment 14 at 41 pounds, segments 15 and 19 at 48.5 pounds, and segments 16 and 20 at 70 pounds. Average 49.82 pounds per cubic foot.

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Figure 15


U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
H. H. BENNETT, Chief
LAKE ISSAQUEENA
SIX MILE CREEK
PICKENS COUNTY
SOUTH CAROLINA
SEDIMENTATION SURVEY OF APRIL 11-17, 1941
G.C. Dobson, Chief, Sedimentation Division, Office of Research
250 0 250 500 750
Scale In Feet
LEGEND
1941 Spillway Crest Line
Original Crest Line
Lake Area Silted Above Crest
R6 Sediment Range
1002 Triangulation Station
5 Segment Number
Thalweg of Original Stream Channel
M.N.
DAM
R1 R2 R3 R4 R5 R6 R7 R8 R9 R10 R11 R12 R13 R14 R15 R16 R17 R18 R19 R20
1000 1002 1003 1004 1005 1006 1007 1008 1009 1010 1011 1012 1013 1015 1016 1017 1018 1019 1020 1021 1022 1023 1024

Little